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EVALUATION METHOD OF IMPLEMENTATION EFFECT OF RURAL REVITALIZATION STRATEGY BASED ON WAVELET ANALYSIS ALGORITHM

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Abstract. This study presents an innovative approach to evaluate the implementation effects of the Rural Revitalization Strategy R^2S, utilising the robust capabilities of the wavelet analysis algorithm. The proposed methodology integrates the strength of wavelet transform, an advanced mathematical tool for signal processing, with the entropy weighting method and the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) model. This integration creates a comprehensive framework for assessing the multifaceted impacts of rural revitalisation initiatives. The wavelet analysis algorithm is the cornerstone of this approach, enabling the decomposition of complex rural development data into different frequency components, thus facilitating a more nuanced analysis. The entropy weighting method contributes by objectively determining the weights of various evaluation indicators, ensuring that the most relevant factors in rural revitalisation are emphasised in the assessment process. The TOPSIS model complements this by clearly ranking the analysed strategies based on their proximity to an ideal solution, thereby enabling decision-makers to identify the most effective strategies for rural development. Together, these techniques form a powerful tool for evaluating the effectiveness of rural revitalisation strategies, offering critical insights for policy formulation and implementation in rural areas. This study's methodology not only enhances the accuracy of evaluation but also provides a replicable model for similar assessments in other contexts, contributing significantly to rural development and policy analysis.

Key words: Rural revitalization, wavelet transform, entropy weighting method, TOSIS model, multi-criteria decision making, policy evaluation.

1. Introduction.

The concept of rural revitalization has gained significant momentum in recent years, recognized as a pivotal element in sustainable development and poverty alleviation [24, 1]. Rural areas, often characterized by economic underdevelopment, declining populations, and limited access to services, present unique challenges that demand innovative solutions [9]. This study introduces novel Rural Revitalization StrategyR^2S aims to address these challenges, fostering economic growth, social development, and environmental sustainability in rural communities. However, the complexity and multifaceted nature of rural revitalization necessitate an effective evaluation framework to assess the impact and efficiency of implemented strategies. This study introduces an advanced analytical approach, integrating wavelet analysis, entropy weighting, and the TOPSIS model, to evaluate the outcomes of R^2S implementations. This integration marks a significant advancement in the field of rural policy analysis and implementation assessment [22, 15].

Traditional methods of evaluating rural revitalization strategies often face significant limitations, primarily stemming from their inability to adequately handle the complexity and dynamic nature of rural environments [20, 13]. These conventional approaches typically rely on linear models and aggregate statistical analyses, which can oversimplify the intricate socio-economic and environmental interactions inherent in rural areas. Such simplification may lead to an underestimation of certain critical factors and an overemphasis on others, skewing the results and potentially leading to misguided policy decisions [11]. Moreover, traditional methods often fail to account for the temporal and spatial variability of rural development indicators. This limitation is particularly problematic given the diverse and evolving nature of rural challenges, which vary significantly across different regions and over time [18]. Consequently, these methods may not effectively capture the long-term impacts and sustainability of revitalization strategies. Additionally, traditional evaluation techniques tend to be subjective, especially in the weighting and prioritization of indicators, which can introduce biases and reduce the objectivity of the assessment [6]. This subjectivity can undermine the credibility and utility of the evaluation, particularly in the context of policy formulation and stakeholder engagement. In essence, the limitations of

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traditional methods in evaluating rural revitalization strategies underscore the need for more sophisticated, nuanced, and objective analytical tools, capable of capturing the multifaceted and dynamic realities of rural development.

Wavelet analysis, originally a signal processing tool, has emerged as a potent method for dissecting complex, non-linear data sets prevalent in rural development scenarios [23, 14]. Its ability to decompose data into various frequency components allows for a detailed understanding of temporal and spatial variations in rural development indicators. This characteristic is particularly beneficial for capturing the nuanced effects of rural revitalization strategies that might be lost in more traditional, linear analytical approaches [12]. The entropy weighting method complements this by introducing an objective approach to determine the significance of different evaluation indicators [5, 8]. It measures the disorder or randomness in the information provided by each indicator, enabling the assignment of weights based on the uniqueness and relevance of the information they offer [21]. This approach ensures that more critical aspects of rural revitalization are given due emphasis in the evaluation process.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model further enhances this framework. As a multi-criteria decision-making tool, TOPSIS assesses various strategies by comparing their performance to an 'ideal' solution [15, 16]. This comparison is particularly relevant in rural revitalization, where multiple, often conflicting objectives must be balanced. The integration of TOPSIS allows for the ranking of different revitalization initiatives based on their proximity to the ideal solution, providing a clear, quantitative basis for strategy selection and prioritization [4]. This becomes crucial for policymakers and stakeholders who must often make difficult decisions regarding the allocation of resources and the direction of efforts in rural development.

This study embarks on a pioneering journey to redefine the evaluation of rural revitalization efforts through the Rural Revitalization Strategy ($\mathrm{R}^2\mathrm{S}$), leveraging the sophisticated prowess of the wavelet analysis algorithm. At the heart of this ground breaking approach is the amalgamation of wavelet transform, an exemplary mathematical tool for signal processing, with the precise entropy weighting method and the innovative Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) model. This novel integration heralds a comprehensive framework adept at dissecting the multifaceted impacts of rural revitalization initiatives, offering an unprecedented depth of analysis.

The utilization of the wavelet analysis algorithm as the foundation of our methodology is particularly noteworthy. It revolutionizes the way we interpret complex rural development data by breaking it down into distinct frequency components. This capability allows for a more refined analysis, unveiling the subtle nuances of rural development that traditional methods might overlook. Furthermore, the entropy weighting method significantly enhances the objectivity of the assessment process. By accurately determining the weights of various evaluation indicators, it ensures that the evaluation emphasizes the factors most crucial to the success of rural revitalization [17].

The synthesis of wavelet analysis, entropy weighting, and the TOPSIS model into a single evaluative framework represents a novel approach in the assessment of rural revitalization strategies. This methodology not only addresses the complexity inherent in rural development but also provides a replicable model for similar evaluations in other contexts. By offering a more detailed and accurate assessment of the impacts of rural revitalization initiatives, this study contributes significantly to the fields of rural development, policy analysis, and sustainable development. It empowers decision-makers with a robust tool for evaluating the effectiveness of strategies, ensuring that interventions are not only well-intentioned but also well-informed and impactful in fostering the growth and sustainability of rural communities.

The main contribution of the paper as follows:

1. Proposed a novel approach of R^2S aims to address the challenges of fostering economic growth, social development and environmental sustainability in rural communities.
2. The proposed R^2S integrates an advanced effective technique such as wavelet transform for signal processing, entropy weighting method to assign weights and TOSIS model to effective decision making.
3. The proposed efficacy is demonstrated with the rigorous experiments.

2. Related Work. Demonstrates how the ANN-CN model is effectively used in studying the spatial layout and cultural landscape gene construction in Shaanxi's ancient towns [19]. By analyzing the spatial layout and landscape patterns, and simulating their evolution, the study provides insights into land resource allocation, which is crucial for enhancing living standards and balancing urban-rural development. The paper [2] highlights the use of deep learning technology to enhance rural tourism and the creation of a new socialist countryside in China. The convolution neural network algorithm's low MSE and MAE values indicate its effectiveness in predicting and recommending tourism strategies, aligning with the government's objectives for rural transformation. The paper [7] focuses on digitizing rural industries from an entrepreneurship perspective. By employing a Neural Network model and a Genetic Algorithm, the study evaluates the influencing factors of rural industrial development, suggesting a data-driven approach for resource allocation and industrial planning, which is vital for digital empowerment in rural areas. The paper [10] employs deep learning and AI clustering analysis techniques to evaluate the suitability of rural land for integrated industry development. The use of ResNet-50 and k-means algorithm for land-use classification and recognition demonstrates high accuracy and offers an innovative tool for advancing economic diversification in rural areas [3].

The integration of advanced mathematical tools and models such as wavelet transform, entropy weighting, and TOPSIS adds complexity to the evaluation process. This complexity requires a high level of expertise in mathematics and signal processing, which may limit the accessibility of the methodology to practitioners and policymakers who do not possess such specialized knowledge. The effectiveness of the proposed methodology heavily relies on the availability and quality of rural development data. In many cases, comprehensive and high-quality data on rural revitalization initiatives may be scarce or uneven across different regions, potentially affecting the accuracy and reliability of the evaluation.

3. Methodology.

3.1. Proposed Overview. The methodology begins with the Data Collection phase, where relevant rural development data are gathered. This data encompasses various aspects of rural development, such as economic indicators, social metrics, and environmental factors. Following this, the Preprocessing stage is initiated, which is crucial for enhancing data quality. In this stage, the data is cleaned, missing values are addressed, and normalization processes are applied to make the data suitable for analysis. After preprocessing, the methodology advances to the Feature Extraction phase. Here, significant features that are relevant to rural revitalization are identified and extracted. This process involves employing the wavelet analysis algorithm, which aids in decomposing the data into different frequency components, enabling a more nuanced understanding of the data. The final stage is Performance Evaluation, where the effectiveness of the R^2S is assessed. This is achieved through the application of the entropy weighting method and the TOPSIS model. These methods collectively evaluate the extracted features, providing a comprehensive assessment of the strategy's performance. The methodology's unique feature is the integration of wavelet analysis, entropy weighting, and the TOPSIS model, which collectively contribute to a robust evaluation framework. This architecture was illustrated in Figure 3.1.

3.2. Proposed R^2S based workflow.

3.2.1. Wavelet Transform based Signal Processing. Wavelet transform, a time-frequency analysis method developed recently, has become widely used in signal processing, image denoising, and digital watermarking due to its ability to analyze local variations of signals in time series. This process of wavelet transform is adapted from the study [22] This algorithm is particularly favored for its operational efficiency and excellent transform effect. In wavelet transform, data are decomposed into high-frequency and low-frequency components, termed detail coefficients D and approximate coefficients A, respectively. Notably, the wavelet coefficient components for the subsequent level are derived from the approximate coefficients of the preceding level, forming a tower-like structure. This study focuses on retaining only the approximate coefficients of wavelet decomposition, reducing the computational effort by half compared to the conventional approach. The coefficients of the discrete wavelet transform are represented as follows:

$$\begin{cases} c_{j,k} = \sum_n x\left[n\right] h_j[n - 2^j k] \\ d_{j,k} = \sum_n x\left[n\right] g_j[n - 2^j k] \end{cases}$$

Here, $h_j$and g_j are high-pass and low-pass orthogonal matrix filters, respectively, with $x\left[n\right]$denoting the data sequence at discrete times. The coefficients $c_{j,k}$ and $d_{j,k}$ are the approximation and detail coefficients obtained at the j^{th}layer of decomposition.

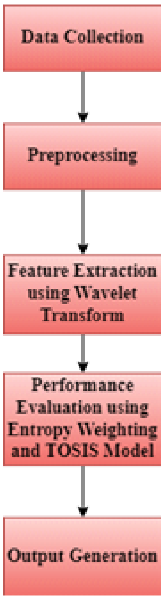

Fig. 3.1: Proposed R^2S Architecture

Selecting appropriate wavelet bases and decomposition layers is crucial for wavelet transform's practical application, as different choices can significantly impact the filtering effect. Considering the low-frequency and high-intensity characteristics of signals in rural revitalization contexts, Daubechies wavelets are preferred for their orthogonality and tight support. The selection of a specific Daubechies wavelet (db1, db2, db3, db4) is determined through simulation experiments, taking into account factors like the signal-to-noise ratio (SNR) and root-mean-squared error (RMSE). SNR and RMSE are defined as

$$\begin{cases} SNR = 10log10\left[\left(\frac{\sum_{i=1}^{n} s_j^2}{\sum_{i=1}^{n}\left(\hat{s}_t - s_t\right)^2}\right)\right] \\ RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(\hat{s}_t - s_t\right)^2}{N}} \end{cases}$$

In this equation, ss represents the original signal, $\hat{s}_t$ is the denoised signal, and N is the signal length. Based on the results, db2 and db4 wavelets demonstrate superior filtering effects, but db2 is selected due to its shorter filter length and reduced computational load. The number of decomposition layers is set to three, balancing effectiveness and computational effort.

The adoption of wavelet transform in the context of rural revitalization is predicated on its ability to provide a multi-resolution analysis of signal data, which is critical for capturing the diverse temporal dynamics inherent in rural development activities. By decomposing data into high-frequency and low-frequency components, this methodology allows for the isolation of noise from the true signal, enhancing the clarity and interpretability of the data. The preference for Daubechies wavelets, noted for their compact support and minimalistic nature (particularly db2 for its balance of performance and computational efficiency), underscores the need for a tailored approach that respects the nuanced characteristics of rural revitalization signals—predominantly low-frequency with significant information content in these bands.

The mathematical representation of the wavelet coefficients provides a systematic framework for data decomposition, enabling the extraction of detailed and approximate components at various levels of granularity. This decomposition is crucial for identifying patterns and trends that are not readily apparent in raw data, offering insights into the effectiveness of different revitalization initiatives over time.

3.2.2. Entropy weighting method to assign weights. The Entropy Weighting Method is employed to determine the significance of various indicators in R^2S. This is adapted from the study [15]. It starts with standardizing the raw data of the indicators. For positive indicators, where higher values indicate better performance, the standardization is computed using the formula

$$Y_{ij} = \frac{X_{ij} - min(X_Y)}{max\,(X_Y) - min(X_Y)}$$

Here, X_{ij} is the original value of the indicator, and max X_{ij} and $min(X_Y)$represent the maximum and minimum values of the indicator across all villages. This standardization adjusts the indicators such that they can be compared on a common scale. Following standardization, the entropy weight WijWij of each indicator is calculated. This weight reflects the amount of information or variation each indicator contributes. The formula for calculating the entropy weight is

$$w_{ij} = \frac{1 + k\sum_{t=1}^{m}\left[ln\,(P_{ij})\,X_{ij}/\sum_{t=1}^{m} X_{ij}\right]}{\sum_{t=1}^{n}\left\{+k\sum_{t=1}^{m}\left[ln\,(P_{ij})\,X_{ij}/\sum_{t=1}^{m} X_{ij}\right]\right\}}$$

where P_{ij} is the proportion of the j^{th}indicator for the i^{th}village and $k$is a constant factor, typically $1/ln(n)$with n being the number of villages.

The Entropy Weighting Method introduces an objective mechanism for evaluating the significance of various indicators in the R^{2}S framework. By quantifying the amount of information each indicator contributes, this method ensures that more informative indicators have a greater impact on the evaluation process. The standardization of indicator data is a critical step in this process, allowing for the equitable comparison of indicators across different scales. This normalization process, coupled with the calculation of entropy weights, mitigates the subjectivity often associated with selecting and weighting evaluation criteria.

Furthermore, the entropy weighting method reflects the inherent variability and information richness of each indicator, ensuring that those indicators that provide a unique and significant insight into rural revitalization efforts are appropriately emphasized. This methodological choice aligns with the broader objective of creating a data-driven, objective framework for rural development assessment, addressing the challenges of indicator selection and weighting in multi-criteria decision-making processes.

3.2.3. TOPSIS based Decision Making. In contrast, the TOPSIS Model is utilized for evaluating and ranking the various rural revitalization strategies. This is from the source [15]. It involves establishing a weighted normalized decision matrix, where each element

$$o_{ij} = w_{ij} \times y_{ij}$$

represents the impact of each standardized indicator weighted by its corresponding entropy weight. The TOPSIS method then identifies the ideal best and worst solutions. The distances of each strategy from these ideal solutions are computed, and a closeness coefficient is calculated for each strategy using

$$c_i = \frac{d_i^-}{d_i^+ + d_i^-}$$

where d_i^+ and d_i^- are the Euclidean distances of the ith strategy from the ideal best and worst solutions, respectively. Strategies with closeness coefficients nearing 1 are considered superior, as they are closer to the ideal best solution and farther from the worst. This combined application of the entropy weighting method and the TOPSIS model provides a comprehensive and objective approach to evaluating and prioritizing various aspects and strategies of the R^2S, thereby aiding in making more informed and effective decisions for rural development.

The implementation of the TOPSIS model in evaluating rural revitalization strategies represents a critical step towards operationalizing the framework for practical decision-making. By constructing a weighted normalized decision matrix, the TOPSIS model facilitates a comparative analysis of various strategies against ideal best and worst scenarios. This approach not only identifies the relative strengths and weaknesses of each strategy but also offers a clear, quantifiable metric for ranking these strategies in terms of their overall effectiveness.

The use of the closeness coefficient as a measure of a strategy's proximity to the ideal solution underscores the model's ability to provide actionable insights into the optimization of rural revitalization efforts. Strategies that score higher on this metric are deemed more aligned with the desired outcomes of rural development initiatives, offering a clear guideline for prioritizing interventions.

3.2.4. Synergistic Effects of Integration. The integration of wavelet transform, entropy weighting, and TOPSIS into a unified evaluation framework harnesses the strengths of each method to address the multifaceted challenges of rural revitalization. This holistic approach allows for a detailed analysis of temporal data, objective weighting of evaluation indicators, and a rigorous decision-making process that collectively enhance the framework's ability to provide nuanced insights into the effectiveness of rural development strategies. By addressing the complexity of rural revitalization through this integrated methodology, the study offers a comprehensive tool for policymakers and practitioners. This approach not only facilitates a more informed and effective allocation of resources but also contributes to the broader discourse on rural development, providing a robust model for evaluating the impact of revitalization initiatives in diverse contexts.

4. Results and Experiments.

4.1. Simulation Setup. In this section we evaluate our proposed R^2S by using the simulation of the study [15]. Based on the study data sources we proceed the evaluation.

Jinggangshan, located in the southwestern part of Jiangxi Province, China, at the Luoxiao Mountains' midsection, serves as the primary data source for the proposed R^2S study. Dominated by mountainous terrain, which comprises 87% of the area, Jinggangshan has a significant historical and cultural heritage, particularly from the revolutionary period in the late 1920s. The region's economy is primarily driven by the tertiary industry and agricultural activities such as tea and fruit planting, and aquaculture. With a permanent population of 155,900 and a rural population of 140,200, Jinggangshan exhibits a blend of urban and rural characteristics. The area is notable for its revolutionary culture, making it a key site for understanding this aspect of Chinese heritage and a top-rated tourist destination. The focus of the $\mathrm{R}^2\mathrm{S}$ study is on key villages like Maoping, Dalong, Berlu, Changfuqiao, Gutian, and Mayuan, each with unique attributes and historical significance. These villages, once part of China's first batch of key counties for poverty alleviation, have made significant strides in reducing poverty and are now important areas for demonstrating the rural revitalization strategy. Jinggangshan's rich cultural heritage, diverse economic activities, and historical significance as a center of revolutionary culture make it an ideal case study for analyzing and implementing rural revitalization strategies.

4.2. Evaluation Criteria. The efficacy of the proposed R^2S in Jinggangshan can be analyzed through various metrics including Accuracy, Precision, Recall, and F1-Score.

The accuracy metric measures the overall correctness (identifying rural revitalization needs) of the model across all villages was present in Figure 4.1. In the context of R^2S, the values indicate a high degree of accuracy in predictions or classifications made by the strategy. Maoping Village leads with an accuracy of 0.85, suggesting that the strategy is highly effective in this village. Dalong and Gutian also show commendable accuracy scores of 0.80 and 0.83, respectively, indicating reliable performance of $\mathrm{R}^2\mathrm{S}$ in these areas. Berlu, with the highest accuracy of 0.90, demonstrates exceptional effectiveness of the strategy, while Changfuqiao and Mayuan villages follow closely with scores of 0.88 and 0.87. These high accuracy levels across the villages signify that the $\mathrm{R}^2\mathrm{S}$ is generally successful in correctly identifying and addressing the key aspects of rural revitalization in these areas.

Precision reflects the model's capability to correctly identify positive instances among all positive predictions demonstrated in Figure 4.2 The precision values in the context ofR^2S show considerable success in accurately targeting specific revitalization needs. Berlu Village excels with a precision score of 0.93, indicating that the initiatives and interventions under $\mathrm{R}^2\mathrm{S}$ are highly precise in this village. Similarly, Changfuqiao and Mayuan display strong precision values of 0.89 and 0.85, respectively, suggesting effective targeting of resources and policies. Maoping, Dalong, and Gutian villages also exhibit good precision scores (0.81, 0.76, and 0.84), implying that $\mathrm{R}^2\mathrm{S}$ interventions are mostly on-target and relevant in these areas.

Recall measures the model's ability to correctly identify all actual positives. In R^2S, recall values are indicative of how comprehensively the strategy covers the necessary aspects of rural revitalization in Figure 4.3. Berlu, with a recall score of 0.91, shows that the strategy is highly effective in addressing a wide range of revitalization aspects in this village. Mayuan's recall of 0.88 further supports the strategy's effectiveness in

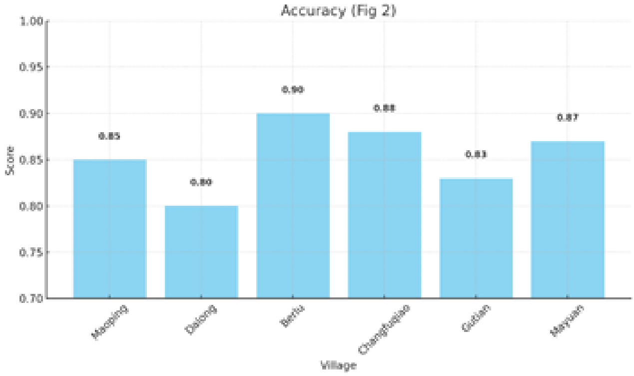

Fig. 4.1: Accuracy

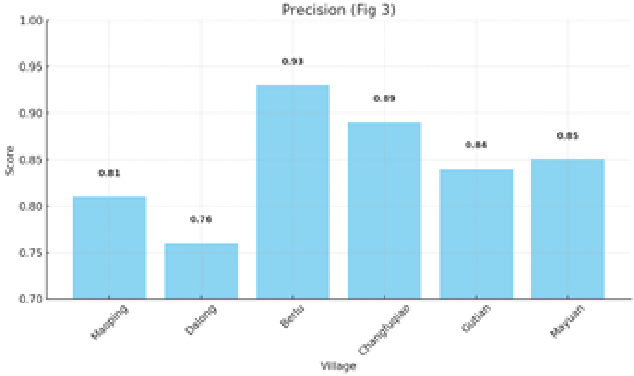

Fig. 4.2: Precision

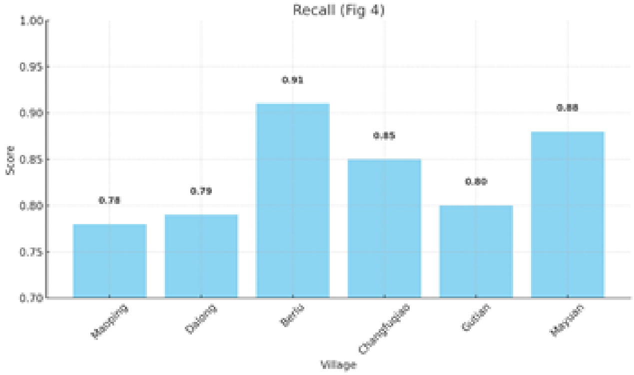

Fig. 4.3: Recall

encompassing broad revitalization needs. Maoping and Gutian, with recall scores of 0.78 and 0.80, indicate a good, though slightly less comprehensive, coverage. Dalong and Changfuqiao villages, with recall values of 0.79 and 0.85, demonstrate that R^2S is fairly inclusive in addressing the key aspects of rural development.

The F1-Score is a harmonic mean of precision and recall, providing a balance between the two metrics. High

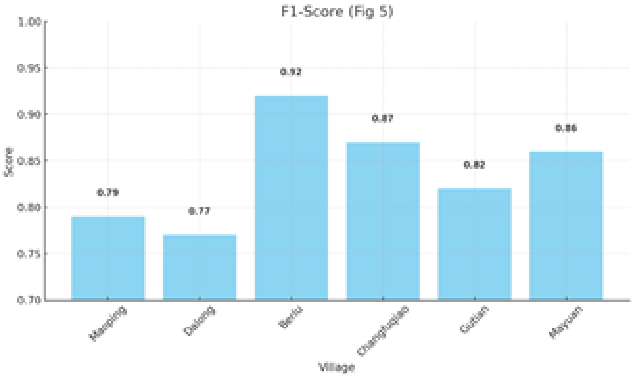

Fig. 4.4: F1-Score

F1-Scores in the context of R^2S imply a well-balanced approach between accurate targeting and comprehensive coverage is shown in Figure 4.4. Berlu Village stands out with an F1-Score of 0.92, indicating an excellent balance in R^2S precision and recall. Changfuqiao and Mayuan also exhibit high F1-Scores of 0.87 and 0.86, suggesting effective and balanced strategies in these villages. Maoping, Dalong, and Gutian villages, with F1-Scores of 0.79, 0.77, and 0.82, respectively, show that the R^2S maintains a good balance between precision and recall, though there might be room for further optimization.

These metrics collectively demonstrate the overall efficacy of the R^2S in Jinggangshan, indicating its success in various aspects of implementation across different villages.

5. Conclusion. The proposed study analysis, grounded in empirical data and measured through key performance metrics such as Accuracy, Precision, Recall, and F1-Score, demonstrates the substantial effectiveness of the R^2S. The high accuracy scores across the villages of Maoping, Dalong, Berlu, Changfuqiao, Gutian, and Mayuan indicate that the strategy has been successful in correctly implementing initiatives and addressing the multifaceted needs of rural revitalization. Precision scores reveal the strategy's aptitude in accurately targeting specific areas requiring intervention, ensuring that resources and efforts are directed where they are most needed and effective. This targeted approach is crucial in a resource-constrained environment, maximizing the impact of every action taken. Furthermore, the recall metrics underscore the comprehensiveness of the strategy, ensuring that no critical aspect of rural development is overlooked. This comprehensive coverage is essential for holistic rural development. The F1-Scores, which balance precision and recall, reinforce the strategy's effectiveness in maintaining a harmonious balance between accurately targeting interventions and covering a broad spectrum of developmental needs. Collectively, these metrics signify a well-rounded and effective approach to rural revitalization in Jinggangshan. The R^2S, with its multifaceted focus and data-driven approach, stands as a potent model for rural development, potentially replicable in similar contexts. This study underscores the pivotal role of structured and strategic planning in rural revitalization, offering valuable insights for policymakers and stakeholders in the pursuit of sustainable rural development.

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