Evaluation of Climate Change Adaptation Strategies of Rural Households in Alpine Ecologically Fragile Regions: A Case Study of the Gannan Plateau Postprint

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Abstract

Climate change has exacerbated livelihood vulnerability among rural households in alpine ecologically fragile areas. In response to climate change, households have adopted various measures, creating an urgent need to evaluate the effectiveness of these adaptation strategies to enable selection of more effective approaches. This study takes the Gannan Plateau as the research area, analyzing characteristics of household adaptation strategies based on household survey data, employing fuzzy comprehensive evaluation to assess the effectiveness of current adaptation strategies, and utilizing a multi-criteria decision-making model to determine optimal climate change adaptation strategies. The results demonstrate: (1) Households in the Gannan Plateau primarily adopt combination strategies to cope with climate change, particularly adjustment-plus-expansion strategies; (2) The climate change adaptation strategies employed by Gannan Plateau households exhibit relatively good effectiveness, with a benefit index of 3.43. Among these, households in agricultural areas show the best adaptation strategy effectiveness, followed by those in agro-pastoral areas, while those in pure pastoral areas show the poorest; (3) The optimal strategies identified by households differ across regions of the Gannan Plateau. Specifically, households in pure pastoral and agro-pastoral areas identify adjustment of agricultural and pastoral structure as the optimal strategy, while households in agricultural areas identify improvement of agricultural and pastoral infrastructure as optimal. Finally, the paper proposes countermeasures and suggestions for improving the effectiveness of household adaptation strategies and issues requiring further attention in future research.

Full Text

Preamble

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Evaluation of Farmers'Climate Change Adaptation Strategies in High-Altitude Ecologically Fragile Regions: A Case Study of the Gannan Plateau

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This study employs fuzzy comprehensive evaluation to analyze the effectiveness of current adaptation strategies and utilizes a multi-criteria decision-making model to identify optimal climate change adaptation strategies.

Abstract

Climate change has intensified the livelihood vulnerability of farmers in high-altitude ecologically fragile regions. To address this challenge, farmers have devised various adaptation strategies. It is therefore crucial to evaluate the effectiveness of these strategies to identify more effective approaches. Taking the Gannan Plateau as the study area, this research investigates 548 households through stratified random sampling and participatory rural appraisal. We analyze the characteristics of farmers' climate change adaptation strategies, evaluate their effectiveness using a fuzzy comprehensive evaluation method, and determine the most effective adaptation strategy through multi-criteria decision-making analysis. The results show that: (1) Most farmers on the Gannan Plateau employ combined strategies to cope with climate change, with 65.30% of households being farmers and 30.21% employing "expansive and accommodating" strategies. Furthermore, farmers' choice of adaptation strategy differs by region. In the pure pastoral area, the most common strategy is reducing livestock numbers, whereas farmers in semi-farming semi-pastoral areas and agricultural areas primarily adopt early pasture transfer and adjusting farming schedules. (2) The overall effectiveness index of adaptation strategies on the Gannan Plateau is 3.43, with social benefits being highest, followed by environmental benefits, and economic benefits being lowest. Further analysis reveals that agricultural area farmers achieve the best adaptation strategy outcomes, followed by semi-farming semi-pastoral areas, with pure pastoral areas showing the worst results. (3) The optimal strategies vary across regions: farmers

in pure pastoral and semi-farming semi-pastoral areas should adjust agricultural and pastoral structures, while agricultural area farmers should improve agricultural and pastoral infrastructure. The study proposes recommendations for enhancing adaptation strategy effectiveness and identifies issues requiring further attention in future research.

Keywords: farmers; climate change adaptation strategies; fuzzy comprehensive evaluation method; multi-criteria decision-making model

1. Data Sources

Field surveys were conducted over several days in the Gannan Plateau. Initially, resource and environmental data were collected at the county level. Subsequently, Participatory Rural Appraisal (PRA) tools, including questionnaires and small group discussions, were employed for household surveys to obtain required data and information. Based on interviews with village officials and farmers during pre-surveys, a questionnaire was designed targeting primarily household heads. To ensure accuracy, Tibetan university students served as language translators, with each household survey taking approximately 30-40 minutes.

Given the vast territory of the Gannan Plateau and dispersed settlement of farmers and herders, interview difficulties were considerable. A total of 548 households were surveyed using stratified random sampling, yielding 548 valid questionnaires. The average age of respondents was 43.24 years, with an average farming experience of 24.18 years and average household size of 4.38 members. The average annual per capita income was ¥5,976.15. Although the sample size was limited, comparison with statistical data from the *Gannan Statistical Yearbook (2013)* revealed that the sample basically reflects the general situation of households in the Gannan Plateau.

The questionnaire covered: (1) basic household information including age and education level of the household head, family size, income and expenditure, and cultivated land and grassland area; (2) impacts of climate change on household livelihoods and adaptation strategies adopted; (3) farmers' evaluations of the economic and environmental benefits of adaptation strategies; and (4) assessments of the effectiveness, flexibility, and responsiveness of various alternative adaptation strategies.

Characteristics of Surveyed Households

2. Methodology

2.1 Evaluation Method for Climate Change Adaptation Strategy Effectiveness

Farmers' evaluation indicators for adaptation strategy effectiveness have strong fuzziness, making quantitative analysis difficult. Fuzzy comprehensive evaluation, based on fuzzy mathematics, offers significant advantages in handling qualitative, uncertain, and incomplete information by converting qualitative assessments into quantitative ones. This study employs fuzzy comprehensive evaluation to analyze the implementation effects of farmers' current climate change adaptation strategies.

The specific steps are as follows:

1. **Establish the indicator set U for evaluating adaptation strategy effectiveness and determine weights W for each indicator.**
2. **Establish the evaluation set V.** The implementation effects of climate change adaptation strategies are divided into five levels: very good, good, average, poor, and very poor. Thus, the evaluation set V = {v_1, v_2, ···, v }.
3. **Quantify the fuzzy membership function.** Based on actual survey data, construct the comprehensive evaluation matrix R. For the g-th indicator u_g, the evaluation R_g = {r_g_1, r_g_2, ···, r_g }, where r_g represents the membership degree of the g-th indicator to the n-th level. The evaluation matrix is formed by individual indicator evaluation vectors R_g (according to the Likert scale).
4. **Establish the evaluation model M ($\cdot$, +) to obtain the fuzzy comprehensive evaluation set B through B = W × R.**
5. **Calculate the comprehensive effectiveness evaluation index P for each indicator using the fuzzy comprehensive evaluation set B and measurement indicators E.** P = B × E^T, where E = {5, 4, 3, 2, 1}.

Indicator System Construction Climate change adaptation involves multiple spatial dimensions. Following principles of comprehensiveness and objectivity in indicator selection, and drawing on previous effectiveness evaluation research [15], this study fully considers the ecological environment of the Gannan Plateau, farmers' livelihood patterns, and the actual impacts of climate change on farmers' livelihoods. Indicators are designed from three dimensions—economic, social, and ecological—to comprehensively reflect adaptation strategy effectiveness, with weights determined through expert consultation.

- **Economic effectiveness:** Measured by changes in household income
- **Social effectiveness:** Measured by changes in employment patterns, climate change awareness, proactivity in responding to climate change, and adaptive capacity

- **Environmental effectiveness:** Measured by changes in grassland and cultivated land quality

Effectiveness Evaluation Indicator System for Farmers' Current Adaptation Strategies

2.2 Multi-Criteria Assessment Model for Climate Change Adaptation Strategies

Multi-Criteria Decision-Making (MCDM) is an integrated evaluation method that ranks various adaptation strategies based on multiple assessment criteria through stakeholder participation. It is highly effective for identifying preferred options to mitigate climate change negative impacts, as it helps reveal the strengths and weaknesses of different strategies. MCDM has been widely applied in climate change adaptation strategy evaluation, such as in assessing water resources climate change impacts and adaptation strategies in Canada' s Georgia Basin [7] and evaluating adaptive measures for water scarcity under climate change in the Hai River Basin [16].

Common MCDM methods include Simple Additive Weighting (SAW), ELimination Et Choix Traduisant la REalité (ELECTRE), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The SAW method assumes attributes are mutually independent and complementary, allowing additive aggregation for overall evaluation. The ELECTRE method determines superiority relationships by measuring the degree of difference between evaluated strategies. The TOPSIS method ranks strategies by their proximity to ideal solutions and can objectively evaluate various adaptation strategies.

This study adopts the TOPSIS method to rank adaptation strategies and identify optimal options, as it clearly reflects the degree of superiority among strategies with a transparent calculation process and operational feasibility.

Determination of Evaluation Criteria and Weights Climate change adaptation aims to reduce adverse impacts or losses from climate risks. Adaptation planning must integrate with local natural resource development, utilization, and ecological environmental protection. Based on extensive research [17, 18] and in consultation with experts, this study selects four evaluation criteria—adaptation effectiveness, cost-efficiency, flexibility, and responsiveness—and assigns quantitative values to each criterion following principles of objectivity and achievability [19].

Assessment Criteria and Weights

TOPSIS Method For q adaptation strategies with p criteria, the original data matrix X = {x_{ij}}*{q×p} is constructed, where x*{ij} represents the value of the j-th criterion for the i-th adaptation strategy. The matrix is normalized using z-score standardization to obtain normalized matrix A = {a_{ij}}_{q×p}.

The positive-ideal solution A^+ and negative-ideal solution A^- are identified from the q adaptation strategies: - $A^+ = \{b_1^+, b_2^+, \cdots, b\_p^+\}$ - $A^- = \{b_1^-, b_2^-, \cdots, b\_p^-\}$

The distances from each adaptation strategy to the positive-ideal and negative-ideal solutions (d_i^+ and d_i^-) are calculated. The relative closeness coefficient C_i for each strategy is obtained as: $C\_i = d\_i^- / (d\_i^+ + d\_i^-)$

Strategies are ranked in descending order of C_i, where $0 \leq C\_i \leq 1$. Higher C_i values indicate better adaptation strategy effectiveness.

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3. Results

3.1 Farmers' Current Adaptation Strategies

To effectively respond to climate change, farmers on the Gannan Plateau have adopted multiple adaptation strategies, which can be categorized into: (1) **expansive strategies** aimed at expanding agricultural and pastoral investment and production scale (e.g., purchasing feed, increasing pesticide and fertilizer inputs); (2) **adjustment strategies** aimed at adapting to climate change through different agricultural and pastoral practices (e.g., artificial grass planting, crop variety improvement, crop structure adjustment); and (3) **contraction strategies** aimed at reducing agricultural and pastoral investment and production scale.

Survey results show that farmers on the Gannan Plateau predominantly employ combined strategies, primarily expansive and adjustment strategies, to cope with climate change. Specific patterns vary by region:

- **Pure pastoral areas:** The most common adaptation measure is reducing livestock numbers (35.80%), followed by purchasing feed (31.48%), and renting pastureland and artificial grass planting (both 27.16%). The adaptation strategy diversification index is 2.48.
- **Semi-farming semi-pastoral areas:** The most common measure is early pasture transfer (44.05%), followed by increasing irrigation (33.33%), and reducing livestock (32.74%). The adaptation strategy diversification index is 2.67, the highest among all regions.
- **Agricultural areas:** The most common measures are early pasture transfer, adjusting farming schedules, and increasing irrigation (all 31.69%), followed by reducing livestock (30.05%). The adaptation strategy diversification index is 2.77.

Climate Change Adaptation Strategies of Farmers in the Gannan Plateau (%)

3.2 Effectiveness of Current Adaptation Strategies

The overall effectiveness index of adaptation strategies adopted by Gannan Plateau farmers is 3.43. Social benefits are highest (3.71), followed by envi-

ronmental benefits (3.40), while economic benefits are lowest (3.25). Further analysis reveals significant regional differences:

- **Pure pastoral areas:** Show the poorest effectiveness with overall index of 3.25
- **Semi-farming semi-pastoral areas:** Moderate effectiveness with index of 3.63
- **Agricultural areas:** Show the best effectiveness with index of 3.39

Economic, social, and environmental benefit indices vary accordingly across regions.

Effectiveness of Farmers' Adaptation Strategies in the Gannan Plateau

3.2.1 Economic Benefits The economic benefit index of adaptation strategies in the Gannan Plateau is 3.25, below the overall effectiveness index. Pure pastoral areas show the poorest economic performance (3.19), followed by semi-farming semi-pastoral areas (3.20), with agricultural areas performing best (3.36). Only 19.65% of pure pastoral farmers believe their adaptation strategies increase household income, compared to 45.33% in agricultural areas. Pure pastoral farmers report that measures such as artificial grass planting increase production costs.

3.2.2 Social Benefits Social benefits index is 3.71, exceeding the overall effectiveness index. The highest benefit is in employment pattern changes (3.82), followed by climate change awareness (3.66), while adaptive capacity shows lower benefits (3.63). Implementation of adaptation strategies has changed production factors and labor allocation, shifting employment from agriculture to non-agricultural sectors and reducing dependence on natural capital, which is most sensitive to climate change.

When asked whether they pay more attention to climate change and respond more proactively after adopting strategies, 69.46% and 66.14% of farmers respectively answered affirmatively. Regarding quality of life and adaptive capacity, 69.84% and 59.34% reported improvements. Agricultural area farmers show the strongest social benefits (3.82), primarily because smaller per capita farmland and higher education levels lead to greater engagement in non-agricultural employment when crops fail due to drought or snow disasters.

3.2.3 Environmental Benefits Environmental benefits index is 3.40, below the overall effectiveness index. The greatest impact is on cultivated land quality (3.38), followed by grassland quality (3.39). While 49.61% and 51.56% of farmers reported improvements in grassland and cultivated land quality respectively, 13.43% and 10.45% reported negative environmental impacts from their strategies.

Agricultural areas show the best environmental benefits (3.46), while semi-farming semi-pastoral areas show the poorest (3.34). This is because agricultural

area farmers have smaller grassland areas but higher education and payment capacity, enabling effective implementation of artificial grass planting and rotational grazing. Semi-farming semi-pastoral and agricultural area farmers also improve cultivated land quality through fertilization and water conservation measures.

3.3 Farmers' Optimal Adaptation Strategy Selection

To better adapt to climate change, more effective strategies are urgently needed, requiring comprehensive consideration of climate risks, socio-economic conditions, and regional development planning. Based on surveys of farmers' adaptation needs and consultation with experts and relevant departments, this study identified seven major adaptation strategies: adjusting agricultural/pastoral structure, adopting new agricultural/pastoral technologies, adjusting agricultural/pastoral scale, improving agricultural/pastoral facilities, developing non-agricultural industries, joining cooperatives, and purchasing insurance.

Using the multi-criteria assessment model, the study evaluated these strategies based on farmer ratings:

- **All surveyed farmers:** Developing non-agricultural industries scored highest (0.743), considered most effective due to perceived advantages in adaptation effectiveness and feasibility (78.60% and 73.20% of farmers rated it highly).
- **Pure pastoral areas:** Adjusting agricultural/pastoral structure is optimal (0.827), with 78.31% and 78.30% of farmers recognizing its superior effectiveness and cost-efficiency.
- **Semi-farming semi-pastoral areas:** Adjusting agricultural/pastoral structure is also optimal (0.748), with 84.94%, 64.46%, and 77.11% rating its effectiveness, responsiveness, and feasibility as superior.
- **Agricultural areas:** Improving agricultural/pastoral facilities is optimal (0.856), with 86.47%, 75.47%, and 72.09% rating its effectiveness, responsiveness, and feasibility as superior.

Assessment Values of Farmers' Climate Change Adaptation Strategies in the Gannan Plateau

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4. Conclusion and Discussion

Understanding the effectiveness of climate change adaptation strategies employed by farmers in ecologically fragile regions is critical for developing effective adaptation policies. This study evaluates adaptation strategy effectiveness and identifies optimal strategies for the Gannan Plateau based on household survey data.

Gannan Plateau farmers predominantly employ combined strategies, primarily adjustment and expansive types, to cope with climate change. This aligns

with Wheeler et al. [20], who note that adjustment and expansive strategies demonstrate strong proactivity and can become mainstream responses to climate change. This pattern is closely related to farmers' perceptions of climate change impacts, government-provided climate information, and subsidy policies, indicating that most Gannan Plateau farmers actively adapt to climate change.

The overall effectiveness index of adaptation strategies is 3.43, with social benefits highest, followed by environmental benefits, and economic benefits lowest. This suggests that strategies primarily enhance social benefits (increased climate change awareness, adaptive capacity, and improved quality of life) rather than economic or environmental benefits.

Significant regional differences exist: agricultural area farmers achieve the best overall effectiveness, while pure pastoral areas show the poorest. This is because agricultural area farmers have higher education levels, greater non-agricultural orientation, stronger capacity to accept new skills and innovate, and higher strategy diversification indices, resulting in stronger risk resistance and lower climate change livelihood vulnerability.

Developing non-agricultural industries is the most effective adaptation strategy for Gannan Plateau farmers, as it diversifies livelihoods and disperses climate risks. With increasing non-agricultural orientation, local farmers increasingly prefer non-agricultural employment to reduce dependence on natural ecosystems severely impacted by climate change.

Optimal strategies differ by region: pure pastoral and semi-farming semi-pastoral areas should focus on adjusting agricultural/pastoral structures, while agricultural areas should prioritize improving agricultural/pastoral facilities. This is because pure pastoral and semi-farming semi-pastoral households derive 69.83% and 53.96% of income from agriculture/pastoralism respectively, with high natural resource dependence and lower education levels (illiteracy and primary education rates of 65.93% and 59.35%). When climate change causes major production losses, these farmers market-oriented selection of high-yield crops and livestock to compensate. In contrast, agricultural areas have complex topography with forests and sloping farmland, where climate change damages infrastructure and dramatically increases production costs (reported by 67.00% of farmers), creating strong demand for infrastructure improvements.

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5. Recommendations and Outlook

Based on these conclusions, effective climate change adaptation in the Gannan Plateau requires multi-party collaboration. Given limited individual farmer capacity to prevent and mitigate climate impacts and the complexity of adaptation as a systematic 工程 [21], government leadership is essential to guide rational decision-making.

1. **Climate Monitoring and Information:** Establish locally-tailored climate monitoring systems to improve medium- and long-term weather forecasting accuracy. This is crucial for optimizing agricultural/pastoral structures and scheduling farming activities. Develop information platforms providing accurate agricultural market and employment information, and strengthen publicity on climate change information to enable timely, planned adaptation.
2. **Financial Support:** Increase small loans to farmers, establish diversified credit mechanisms, implement preferential tax policies and loan subsidies, and continuously increase government climate adaptation funding to provide material foundations for adaptation while increasing farmers' transfer income.
3. **Technology and Training:** Actively develop and promote new technologies, conduct practical technical skills training, provide management guidance, and develop simple, low-investment, high-return agricultural/pastoral technologies. Introduce superior seed varieties and livestock breeding technologies to incentivize adoption of new agricultural/pastoral techniques.

Evaluating adaptation strategy effectiveness is crucial for exploring effective adaptation strategies and models in high-altitude ecologically fragile regions. Future research should strengthen:

- **Integrated strategy evaluation:** This study identified optimal strategies but should also consider sub-optimal and complementary strategies, analyzing integrated innovation to combine various micro-level strategies in optimal configurations.
- **Feasibility testing:** Develop farmer-level adaptation strategy assessment tools, examining feasibility of different adaptive behaviors considering spatial-temporal characteristics of climate impacts, information asymmetry, and short-term constraints.
- **Adaptive practice development:** Further develop practical adaptation solutions, recognizing competitive yet beneficial relationships among different strategies and their interactions.

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Note: Figure translations are in progress. See original paper for figures.