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Research article

SDGs-oriented evaluation of the sustainability of rural human settlement environment in Zhejiang, China

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A B S T R A C T

Sustainable development of rural has become an essential global plan. Habitat sustainability assessment of rural is a critical management tool to grasp the development status of rural in real-time and enable dynamic adjustment of policies. This paper combines the 2030 Sustainable Development Goals (SDGs) with the entropy weight method, TOPSIS, and grey correlation analysis to construct a multi-criteria decision-making (MCDM) evaluation model, which is finally used to assess the sustainability of the rural human settlement environment. Finally, this paper uses the rural of 11 prefecture-level cities in Zhejiang Province in 2021 as a case study for rural human settlement environment sustainability evaluation. The results show that the overall rural human settlement environment sustainability level in Zhejiang Province is better than in most regions in China. Hangzhou has the best rural human settlement environment sustainability, and Zhoushan has the worst. In addition, the production environment factor is the critical factor that constrains sustainability. The study results provide references and guidance to policymakers for sustainable development initiatives.

1. Introduction

As an essential carrier of human habitation, rural areas are closely related to people's lives. According to the United Nations, rural people (farmers) account for more than half of the global population, and poor farmers account for 79% of the global poor. The poverty rate in rural areas is more than three times higher than in urban areas. Of the 2 billion people worldwide without access to essential health services, 70% live in rural areas. Rural areas have about 75% energy access, compared to 96% in urban areas. In China, as of 2021, the total rural population is 509.79 million, or 36.1% of the total population, and in Zhejiang, the total rural population is 17.97 million, or 27.9% of the total population. Countries around the world have experienced a decline in rural human settlement environments. In countries such as the United States, Canada, Sweden, Australia, China, and Japan, rapid urbanization has severely exacerbated demographic, social, and environmental conflicts in rural areas, and the countryside is gradually experiencing a decline. (Wood, R. E. (2008),Markey, S. et al. (2008),Luck, G. et al. (2010),Hedlund, M. et al. (2015),Li, Y. et al. (2018),Li, Y. et al. (2019)) [1–6] There are many reasons for the decline of the rural human settlement environment, mainly social problems caused by economic issues. The population in rural areas continues to flock to cities with urbanization, resulting in a reduced labor force, a further

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shrinking economy, and a further increase in the gap between urban and rural areas. (Champion, T., et al. (2006), Amcoff, J., et al. (2007),Luck, G. W. et al. (2010)) [7–9] In addition, it is also partly due to policies, such as China's focus on urban development over a period, which eventually led to the "hollowing out" of the countryside and widened the gap between urban and rural areas. (Feng Juan. (2022), Han Zhanbing. (2022)) [10,11] Generally speaking, both urban and rural areas are inseparable parts of the rural human settlement environment, and they are the same. That is why more and more countries are embarking on urban-rural integration.

After 30 years of urbanization in China, cities' sustainability level is increasing. However, in rural areas, the economic level, people's life, and ecological environment are gradually becoming more problematic, and the sustainability of rural areas needs to be improved. For a better and more sustainable future blueprint for all, it is vital to address the three dimensions of development: economic, social, and ecological environment. (Seker, S., & Kahraman, C. (2021)) [12] The United Nations proposed the following goals in 2015: No poverty (SDGs1), Zero hunger (SDGs2), Good health and well-being (SDGs3), Quality Education (SDGs4), Decent work and economic growth (SDGs8), Industry, innovation and infrastructure (SDGs9), Sustainable cities and communities (SDGs11), Responsible consumption and production (SDGs12), Climate Action (SDGs13), and Life on land (SDGs15), all of which are related to sustainable human settlements, while rapid urbanization has rapidly concentrated factors of production such as population, land, and capital in cities, which hinders the sustainability of rural development. (UNITED NATIONS PUBLICATIONS. (2018), The United Nations. (2015)) [13,14] This leads to the following question, how to solve the sustainability problem of rural human settlement environment?

In order to achieve integrated urban-rural development and promote the equal exchange of production factors such as population, land, and capital and the equitable distribution of public resource allocation, the Chinese government has made integrated urban-rural development the primary way to achieve the goal of rural revitalization in the new era. The core of rural revitalization lies in the sustainable development of the human environment in rural areas. Liu, Y. (2018) argues that the current imbalance in the urban-rural spatial structure has led to many land problems, which hinder the sustainability of land use. If these problems are to be solved, there is an urgent need to implement the rural revitalization strategy. Rural revitalization strategies mainly address the main social conflicts facing rural development, such as population, land industry, and other vital issues, thus improving the sustainability and competitiveness of rural area systems. (Liu, Y. (2018)) [15] Li, Y (2018) et al. The idea is to promote ruralization and urbanization in China. Ruralization provides a platform for rural residents to work or start their businesses while caring for their families and farms. In this process, small towns can act as bridges to transport education, health care, information, and administrative services to remote villages. In addition, institutional reforms are needed to allocate more resources to rural areas and local governments that provide better public services. (Li, Y., Jia et al. (2018)) [16].

Based on the United Nations' sustainable development goals and the studies of experts and scholars in China, this study argues that sustainable human settlements development aims to balance the economic, social, and ecological environments. Assessing the sustainability of the habitat in rural areas is critical problem-solving in this paper.

The significance of sustainability assessment is to present an image of sustainability in rural areas using different indicators. Currently, sustainability assessment tools are widely used in urban development. The steps of the multi-attribute decision model for the sustainability of cities are mainly the construction of the indicator system, the establishment of weights, the calculation of each indicator, and the ranking of indicators. (Seker, S., & Kahraman, C. (2021)) [12] There are few studies on sustainability evaluation in rural areas, and urban sustainability evaluation has a specific reference significance. In terms of urban sustainability indicator system construction, Lynch A. J. et al. Summarized 22 primary and 377 secondary indicators to measure the sustainable development of U.S. cities through their research. (Lynch, A. J. et al. (2011)) [17] Shen, L. Y et al. found the dimensions of sustainability evaluation through nine different project studies, which are environmental, social, economic, and governance. (Shen, L. Y. et al. (2011)) [18] Yigitcanlar, T. et al. Developed urban sustainability evaluation models in land use, infrastructure, spatial environment, and transportation to facilitate sustainable urban development. (Yigitcanlar, T., & Dur, F. (2010)) [19] González-García, S. et al. Propose a sustainability assessment methodology based on 38 indicators that include the three pillars of sustainability: social, economic, and environmental. (González-García, S. et al. (2019).) [20] In constructing a system of indicators of rural sustainability, Bigdeli Rad V et al. consider security, education, social participation, population, health, leisure, social responsibility, satisfaction with services, and a sense of belonging to a place as components of rural sustainability. (Bigdeli Rad, V., & Maleki, S. (2020)) [21] Cozzi, M. proposed an evaluation methodology for spatial decision-making with indicators including four dimensions of long-term ecological sustainability, the satisfaction of basic human needs, satisfaction of the needs of future generations, and equity between future generations to measure rural sustainability in southern Italy. (Cozzi, M. et al. (2020)) [22] Shi, J. proposed five dimensions for rural sustainability development in China: industrial prosperity, ecological livability, rural civilization, and rural revitalization, and analyzed the level of rural development in 31 provincial administrative regions of China from 2000 to 2020. (Shi J. et al. (2022)) [23].

For the construction of the sustainability indicator system, part of the study refers to the Sustainable Development Goals (SDGs) released by the United Nations in 2015. With 17 SDGs (poverty eradication, zero Hunger, good health and well-being, clean water and sanitation, affordable and clean energy, decent jobs and economic growth, industry, innovation and infrastructure, inequality reduction, and sustainable cities and communities), the UN aims to thoroughly address the social, economic and environmental dimensions of development in an integrated manner between 2015 and 2030, shifting to a sustainable development path. (Chen, R. et al. (2021), Xiao Y. et al. (2018).) [24,25] Some studies consider the SDGs as "making cities and rural human settlement environment inclusive, safe, resilient and sustainable," with 11 goals, each with negotiated indicators. (Klopp, J. et al. (2017), Diaz-Sarachaga, J. M et al. (2019), Baffoe, G. et al. (2021)) [26–28] In addition to the general study of SDGs indicators, some scholars have also studied the sustainability of individual indicators. For example, SDGs −9 and SDGs −11. (Chopra, M. et al. (2021), Abastante, F. et al. (2021)) [29,30].

After the index system is established, the research methods for evaluation need to be selected. Research methods for the general comprehensive evaluation of rural human settlement environment sustainability studies are divided into subjective, objective, and mixed methods. (Pena, J. et al. (2020)) [31] Decision-makers mainly use subjective methods to express their opinions about the attributes and thus generate weights based on subjectivity. Such as hierarchical analysis and the Delphi method. (Lee, J. H., & Lim, S. (2018), Musa, H. D. et al. (2019)) [32,33] The objective method is to generate weights through a series of objective data. Such as the Grey relational analysis method and entropy weighting method. (Yi, P., Li et al. (2021), Purvis, B. et al. (2019)) [34,35] The hybrid method combines the two previous methods. Such as ANP-TOPSIS, IT2F-AHP, and COPRAS. (Ozkaya, G., & Erdin, C. (2020), Kusakci, S. et al. (2022)) [36,37] In summary, assessing rural human settlement environment sustainability can be considered an MCDM problem. However, current rural sustainability evaluation studies must be more comprehensive for applying multi-attribute decision-making methods, and many evaluation methods need certain limitations. For example, using an objective mixed method, the MCDM approach has been applied more to evaluate urban sustainability, less to rural areas, and even less to study rural human settlement environment sustainability. This study used a mixed Entropy-weighting TOPSIS-GRA method to assess rural human settlement environment sustainability objectively.

Previous studies of rural sustainability and indicator evaluation have shown that rural sustainability has the following characteristics. (Vaishar, A. et al. (2023), (Liu, X. et al. (2022), (Lin, R. et al. (2022), Zhu, X. et al. (2022), Li, Q. et al. (2022), Wang, L. et al. (2022), (Abreu, I. et al. (2020), (Abreu, I. et al. (2019), (Martínez, P. F. et al. (2022), (ROGELJ, M. J. et al. (2022), (Rey-Alvite, A. et al. (2022), Harrington, L. M. B. (2016), Lam, D. P., et al. (2020)) [38–42,42,43–49]First, sustainability indicators of villages need to cover mainly economic, social, and environmental aspects. There are interactions among the sub-indicators under its three aspects. Second, rural sustainability is directly related to citizen participation, which can balance economic, social, and environmental aspects. Third, how to deal with the relationship between ecological and environmental changes and production is a new problem facing sustainable rural development. In summary, rural sustainability can be summarized as rural development that balances economic, social, and environmental aspects while meeting the interests of people of different generations.

Compared with previous studies, this study has three main new objectives: (1) In terms of research methodology, this paper uses a mixed method Entropy-weighting TOPSIS-GRA to establish a set of objective evaluation methods for the sustainability of rural human settlement environment. The use of comparative evaluation methods facilitates the inclusiveness of decision-making. (2) In terms of

Table 1
SDGs-based sustainability evaluation index system of rural human settlement environment

Dimension	Code	Criteria	Unit	Corresponding to the targets in the SDGs
Productive Environment	B1	Agricultural output value per capita in rural areas	Yuan	Goal 8: Decent Work and Economic Growth
	B2	The total output value of the primary industry	100 million Yuan	Goal 8: Decent Work and Economic Growth
	B3	The total output value of agriculture, forestry, animal husbandry, and fishery	100 million Yuan	Goal 8: Decent Work and Economic Growth
	B4	Grain productivity	Tons/thousand hectares	Goal 2: Zero Hunger
	B5	Effective irrigated area	thousand hectares	Goal 8: Decent Work and Economic Growth
Living Environment	B6	Per capita disposable income of rural households	Yuan	Goal 1: No Poverty
	B7	The ratio of disposable income per capita of urban and rural residents	%	Goal 1: No Poverty
	B8	The proportion of rural residents who regularly participate in sports and exercise	%	Goal 3: Good Health And Well-being
	B9	The proportion of townships with elderly places	%	Goal 11: Sustainable Cities and Communities
	B10	Per capita consumption expenditure in rural areas	%	Goal 8: Decent Work and Economic Growth
	B11	Per capita cultural and entertainment consumption expenditure of rural residents	Yuan	Goal 4: Quality Education
	B12	The average number of village health rooms per 10,000 people	Number	Goal 3: Good Health And Well-being
	B13	The average number of cell phones per 100 households	Number	Goal 9: Industry, Innovation, and Infrastructure
	B14	Housing construction area per capita	m^2	Goal 11: Sustainable Cities and Communities
	B15	Per capita electricity consumption in rural areas	kWh/person	Goal 11: Sustainable Cities and Communities
Ecological Environment	B16	Rural sanitary toilet penetration rate	%	Goal 11: Sustainable Cities and Communities
	B17	Amount of agricultural fertilizer used	Tons	Goal 12: Responsible Consumption and Production
	B18	Amount of pesticides used	Tons	Goal 12: Responsible Consumption and Production
	B19	Rate of good ambient air quality	%	Goal 13: Climate Action
	B20	Forest coverage rate	%	Goal 15: Life On Land

sustainability indicators, compared with traditional indicators, the indicators in this paper are more scientific and comprehensive by combining with the UN 2030 Sustainable Development Goals. (3) In terms of research region selection, this paper selects Zhejiang province in China, which is an eastern coastal province with a particular foundation in the economy but available land resources and has a certain similarity with other regions in China, and the study of its human settlements sustainability is beneficial for the reference of other provinces and has strong replicability. In summary, this study proposes the following research hypotheses: (1)The level of economic development in rural areas positively correlates with the sustainability of rural habitats. (2)The scientificity of decision-making of government departments in rural areas is positively correlated with the sustainability of rural habitat; (3)The elements of the rural natural ecological environment are positively correlated with the sustainability of rural habitat.

Based on the above analysis, the rest of this paper is as follows: Section II proposes constructing an indicator evaluation system incorporating the UN 2030 Sustainable Development Goals. A new evaluation model of the rural human settlement environment is proposed in Section III. Section IV conducts an empirical study of the rural areas of 11 prefecture-level cities in Zhejiang Province and describes the evaluation results and analysis. Section V outlines the discussion and policy recommendations, and Section VI presents the conclusions and recommendations for future research.

2. Construction of sustainability evaluation index system of rural human settlement environment

In order to promote rural development in a sustainable direction, this paper establishes a comprehensive and multi-faceted evaluation model. This evaluation system is people-centered, and the indicators are established through policy literature analysis and information data collection in conjunction with the United Nations Sustainable Development Goals (SDGs). The SDGs aim to shift to a sustainable development path by thoroughly addressing the social, economic, and environmental dimensions of development in an integrated manner from 2015 to 2030. The goal is not only to achieve economic growth but also to meet the needs of society, promote social development and ecological and environmental protection, and achieve green and sustainable development. The indicators of sustainable development are identified in combination with Goal 1: No Poverty, Goal 2: Zero Hunger, Goal 3: Good Health And Well-being, Goal 4: Quality Education, Goal 8: Decent Work and Economic Growth, Goal 9: Industry, Innovation, and Infrastructure, Goal 11: Sustainable Cities and Communities, Goal 12: Responsible Consumption and Production, Goal 13: Climate Action, and Goal 15: Life On Land. Among them, Goal 11 (Sustainable Cities and Communities) is focused on infrastructure, living environment, and other issues and covers more indicators with the studied indicator system. (UNITED NATIONS PUBLICATIONS. (2018), The United Nations. (2015)) [13,14] The model was finally determined from three dimensions and 20 indicators of the production environment, living environment, and ecological environment, as shown in Table 1. All indicators are further divided into cost indicators and benefits indicators. The smaller the value of cost indicators, the higher their sustainability level. The cost indicators are the ratio of per capita disposable income of urban and rural residents, the amount of fertilizer used in agriculture, and the amount of pesticide used, and the rest are benefit indicators. The model covers almost all issues related to “people” and “society” to assess the sustainability of the rural human settlement environment.

2.1. Productive environment

The production environment is a significant “blood-making” force to enhance the sustainability of the rural human settlement environment. It is also an important subject to promote the internal circulation system. The production environment reflects the economic development of the countryside. It is the basis for developing a rural human settlement environment, representing the rural economy and production technology level. It corresponds to Goal 2 (Zero Hunger) and Goal 8 (Decent Work and Economic Growth) of sustainable development. The main goal of Goal 8 is to promote inclusive and sustainable economic growth, employment, and decent work for all. The main goal of Goal 2 is to end Hunger, achieve food security, improve nutrition and promote sustainable agriculture. (UNITED NATIONS PUBLICATIONS. (2018), The United Nations. (2015)) [13,14] The above goals correspond more to the productive environment part of this study. Therefore, the leading indicators of the production environment are Agricultural output value per capita in rural areas, Total output value of the primary industry, Total output value of agriculture, forestry, animal husbandry and fishery, Grain productivity, and Effective irrigated area, all of which are benefit indicators.

2.2. Living environment

The living environment is a carrier for the use of living space and living consumption behavior in the countryside and is an important driving force for sustainable rural development. Living environment indicators can reflect the villagers’ life happiness index and directly reflect the sustainable level of the rural human settlement environment. Corresponding to Sustainable Development, Goal 1 (No Poverty), Goal 3 (Good Health And Well-being), Goal 4 (Quality Education), Goal 8 (Decent Work and Economic Growth), Goal 9 (Industry, Innovation, and Infrastructure), and Goal 11(Sustainable Cities and Communities). The main goal of Goal 1 is to eradicate poverty in all its forms everywhere. The main goal of Goal 3 is to ensure healthy lifestyles and promote the well-being of people of all ages. The main goal of Goal 4 is to ensure inclusive, equitable, and quality education and promote lifelong learning opportunities for all. Goal 9 main objective is to build risk-resilient infrastructure, promote inclusive and sustainable industries, and foster innovation. The main objective of Goal 11 is to build inclusive, safe, risk-resilient, and sustainable cities and human settlements. (UNITED NATIONS PUBLICATIONS. (2018), The United Nations. (2015)) [13,14] The above goals correspond more to the living environment part of this study. Therefore, the immediate living environment indicators are the Per capita disposable income of rural households, the ratio of per capita disposable income of urban and rural residents, the proportion of rural residents who regularly participate in sports and exercise, the proportion of townships with elderly places, the per capita consumption expenditure in rural areas, the per capita cultural and entertainment consumption expenditure of rural residents, the average number of village health rooms per 10,000 people, the average number of cell phones per 100 households, the per capita housing construction area, the per capita electricity consumption in rural areas. The ratio of per capita disposable income of urban and rural residents is a cost indicator, and the rest are benefit indicators.

2.3. Ecological environment

Ecological environment mainly refers to measuring the countryside's ecological and green development levels, both in the context of a sustainable society. The ecological environment is the essential condition for the survival and development of the countryside and is the basis for the economic development of the countryside. This corresponds to Sustainable Development Goal 11 (Sustainable Cities and Communities), Goal 12 (Responsible Consumption and Production), Goal 13 (Climate Action), and Goal 15 (Life On Land). The main goal of Goal 12 is to ensure sustainable consumption and production patterns. The main objective of Goal 13 is to take urgent action to address climate change and its impacts. The main objectives of Goal 15 are to protect, restore and promote sustainable use of terrestrial ecosystems, sustainable forest management, combat desertification, halt and reverse land degradation, and halt the loss of biodiversity. (UNITED NATIONS PUBLICATIONS. (2018), The United Nations. (2015)) [13,14] The above objectives have more ecological counterparts to this study. Therefore, the ecological environment indicators are mainly the rural sanitary toilet penetration rate, Amount of agricultural fertilizer used, Amount of pesticides used, Rate of good ambient air quality, and Forest coverage rate. The amount of agricultural fertilizer and pesticide use are cost indicators, and the rest are benefit indicators.

3. Research methodology

For the sustainability evaluation of rural human settlement environment, this study uses the improved TOPSIS method and the entropy weighting method to determine the weights of each index of the evaluation system while using the Grey relational analysis to reduce the uncertainty of subjective judgment, thus enhancing the objectivity of the overall evaluation.

3.1. Determination of index weights using the entropy weight method

The entropy weighting method is an objective assignment method. In the sustainability evaluation process, weights are calculated based on each indicator's attributes and the dispersion of statistical data. The evaluation idea of the entropy weighting method is that the greater the difference in the value of an evaluation object in a particular indicator, the more critical that object is and the greater the weight value. According to the degree of variation of indicators, the weight value of each indicator can be objectively calculated to provide a more reliable basis for the comprehensive evaluation of multiple indicators. The steps for calculating the weights are as follows.

Step 1: Select the statistical data according to the evaluation index system and construct the initial matrix with m evaluation objects, n evaluation indexes, r_{ij} $(1 \leq \mathrm{i} \leq \mathrm{m}, 1 \leq \mathrm{j} \leq \mathrm{n})$ as the original data of the i items under the j indicators, and its initial matrix R is as follows.

$$\mathrm{R} = \left\{ \begin{matrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & r_{ij} & \cdots \\ \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{matrix} \right\} \tag{1}$$

Step 2: Normalize the primed matrix $\mathrm{R} = (r_{ij})_{mn}$ to the data range of 0–1. The normalized matrix $\mathrm{A} = (a_{ij})_{mn}$ is obtained. If j is a benefit indicator, it is processed according to Equation (2); If j is a cost indicator, it is processed according to Equation (3).

$$\begin{cases} \mathrm{a_{ij}} = \dfrac{\mathrm{r_{ij}} - \min \mathrm{a_{ij}}}{\max \mathrm{a_{ij}} - \min \mathrm{a_{ij}}} & \max \mathrm{a_{ij}} \neq \min \mathrm{a_{ij}} \\ \mathrm{a_{ij}} = 1 & \max \mathrm{a_{ij}} = \min \mathrm{a_{ij}} \end{cases} \tag{2}$$

$$\begin{cases} \mathrm{a_{ij}} = \dfrac{\max \mathrm{a_{ij}} - \mathrm{r_{ij}}}{\max \mathrm{a_{ij}} - \min \mathrm{a_{ij}}} & \max \mathrm{a_{ij}} \neq \min \mathrm{a_{ij}} \\ \mathrm{a_{ij}} = 1 & \max \mathrm{a_{ij}} = \min \mathrm{a_{ij}} \end{cases} \tag{3}$$

Step 3: Calculate the weight p_{ij} of the i sample under the j indicator and consider it as the probability used in the relative entropy calculation:

$$p_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \quad (4)$$

Step 4: Calculate the entropy value of the j indicator e_j:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij} \ln p_{ij} (j = 1, 2, 3, \ldots, m) \quad (5)$$

Step 5: Calculate the defined information utility value d_j for each indicator. If e_j is smaller, the greater the information entropy of the j indicator, the greater the corresponding information quantity, indicating that the indicator has a more significant impact on the sustainability of the rural human settlement environment. Conversely, the larger e_j is, the smaller the information entropy of the j indicator and the smaller the corresponding amount of information. The formula for calculating the information utility value d_j is as follows.

$$d_j = 1 - e_j \quad (6)$$

Step 6: Normalize the information utility values to obtain the entropy weight w_j for each indicator.

$$w_j = \frac{h_j}{\sum_{j=1}^{n} h_j} \quad (7)$$

3.2. Analysis using TOPSIS and grey correlation analysis

The combination of the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) and the Grey relational analysis (GRA) method was used in this study. The improved TOPSIS method is used to evaluate the relative proximity between points and ideal solution points so that the level of rural sustainability can be ranked according to the relative proximity. (Chen, P. (2021), Chakraborty, S. (2022), Ding, S. et al. (2023), Baldi, M. S. et al. (2023), Dimitriou, D. et al. (2022)) [50–54]The Grey relational analysis method (GRA) is an objective multi-factor method that analyzes the degree of correlation between factors based on similarity or dissimilarity. (Kuo, Y. et al. (2008), Zheng, Q. J. et al. (2023), (Javed, S. A. et al. (2022), (Cao, W. et al. (2022), (Tao, J. et al. (2022)) [55–59] The TOPSIS-GRA Methods has more applications in other disciplines, such as the field of cleaner production, sustainable urban development, and carbon emissions and urbanization. (Dong, H et al. (2022), Zhao, Y. et al. (2022), Rehman, E. et al. (2022)) [60–62].

The steps of the analysis using TOPSIS and Grey relational analysis are as follows. First, the positive and negative ideal solutions for the sustainability of the rural human settlement environment were determined by TOPSIS. Secondly, the evaluation indexes of each prefecture-level city's rural human settlement environment were determined and compared with the positive and negative ideal solutions using Grey relational analysis. Finally, the sustainability of the rural human settlement environment between cities was ranked using Grey relational analysis.

Step 1: Normalize the decision matrix R = $(r_{ij})_{mn}$ in Equation (1) to obtain the normalization matrix Z = $(z_{ij})_{mn}$, where z_{ij} is as follows:

$$z_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} {r_{ij}}^2}} (1 \le \mathrm{i} \le \mathrm{m}\ ,\ 1 \le \mathrm{j} \le \mathrm{n}) \quad (8)$$

Step 2: Calculate the obtained weights w=(w_1, w_2, …, w_n) according to the entropy weight method, and multiply them with the normalized decision matrix to obtain the weighted decision evaluation matrix X = $\{x_{ij}\}$.

$$x_{ij} = w_j * z_{ij}, (1 \le \mathrm{i} \le \mathrm{m}, 1 \le \mathrm{j} \le \mathrm{n}) \quad (9)$$

Step 3: Calculate the positive ideal solution x^+ and the negative ideal solution x^- for each indicator as follows.

$$x^+ = \left\{ \left(max_i\, x_{ij} \,\middle|\, j \in J^+ \right),\ \left(min_i\, x_{ij} \,\middle|\, j \in J^- \right) \right\} = \left(\mathrm{r}_1^+, \mathrm{r}_2^+, \ldots, \mathrm{r}_\mathrm{n}^+\right), (1 \le \mathrm{i} \le \mathrm{m}) \quad (10)$$

$$x^- = \left\{ \left(min_i\, x_{ij} \,\middle|\, j \in J^+ \right),\ \left(max_i\, x_{ij} \,\middle|\, j \in J^- \right) \right\} = \left(\mathrm{r}_1^-, \mathrm{r}_2^-, \ldots, \mathrm{r}_\mathrm{n}^-\right), (1 \le \mathrm{i} \le \mathrm{m}) \quad (11)$$

The positive ideal solution is an optimal plan representing the city's rural area with the best sustainability in the ideal, cf. Equation (10); the negative ideal solution is the worst plan representing the city's rural area with the worst sustainability in the ideal, cf—equation (11).

Step 4: Calculate the distances from each object to the positive and negative ideal solutions, respectively. The distance from object x_i to the positive ideal solution is Equation (12); the distance from object x_i to the negative ideal solution is Equation (13).

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(x_{ij} - x_j^+\right)^2}, (1 \le \mathrm{i} \le \mathrm{m}\ ,\ 1 \le \mathrm{j} \le \mathrm{n}) \tag{12}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(x_{ij} - x_j^-\right)^2}, (1 \le \mathrm{i} \le \mathrm{m}\ ,\ 1 \le \mathrm{j} \le \mathrm{n}) \tag{13}$$

Step 5: The Grey relational analysis is used to analyze and calculate the grey correlation coefficient of indicator j for rural i of a city. The grey correlation coefficient with a positive ideal solution is referred to as equation (14); the grey correlation coefficient with a negative ideal solution is referred to as equation (15). ξ is a distinguishing coefficient, ξ ∈ [0,1]. Usually, the distinguishing coefficient is 0.5. The final grey correlation coefficient matrix $Q^+ = (q_{ij}^+)_{m\times n}$ and $Q^- = (q_{ij}^-)_{m\times n}$ with the following reference equations.

$$q_{ij}^+ = \frac{\min_i \min_j \left|x^+ - x_{ij}\right| + \xi \max_i \max_j \left|x^+ - x_{ij}\right|}{\left|x^+ - x_{ij}\right| + \xi \max_i \max_j \left|x^+ - x_{ij}\right|} \tag{14}$$

$$q_{ij}^- = \frac{\min_i \min_j \left|x^- - x_{ij}\right| + \xi \max_i \max_j \left|x^- - x_{ij}\right|}{\left|x^- - x_{ij}\right| + \xi \max_i \max_j \left|x^- - x_{ij}\right|} \tag{15}$$

Step 6: The grey correlation analysis is used to analyze and calculate the grey correlation degree of indicator *j* of rural *i* of a city. The grey correlation degree with the positive ideal solution is referred to as Equation (16); the grey correlation degree with the negative ideal solution is referred to as Equation (17).

$$q_i^+ = \frac{1}{n}\sum_{j=1}^{n} q_{ij}^+, (1 \le \mathrm{i} \le \mathrm{m}) \tag{16}$$

$$q_i^- = \frac{1}{n}\sum_{j=1}^{n} q_{ij}^-, (1 \le \mathrm{i} \le \mathrm{m}) \tag{17}$$

Step 7: D_i^+ and D_i^- are dimensionless indicators of Euclidean distance d_i^+, d_i^-.Similarly, the exact meaning is given to Q_i^+ and Q_i^- (18)–(21) for details.

$$D_i^+ = d_i^+ \big/ \max\left\{d_i^+\right\}, (1 \le \mathrm{i} \le \mathrm{m}) \tag{18}$$

$$D_i^- = d_i^- \big/ \max\left\{d_i^-\right\}, (1 \le \mathrm{i} \le \mathrm{m}) \tag{19}$$

$$Q_i^+ = q_i^+ \big/ \max\left\{q_i^+\right\}, (1 \le \mathrm{i} \le \mathrm{m}) \tag{20}$$

$$Q_i^- = q_i^- \big/ \max\left\{q_i^-\right\}, (1 \le \mathrm{i} \le \mathrm{m}) \tag{21}$$

Step 8: Calculate the relative proximity of the evaluation unit to the "ideal solution."

$$S_i^+ = \alpha d_i^- + \beta q_i^+, (1 \le \mathrm{i} \le \mathrm{m}) \tag{22}$$

$$S_i^- = \alpha d_i^- + \beta q_i^+, (1 \le \mathrm{i} \le \mathrm{m}) \tag{23}$$

$\alpha + \beta = 1, \alpha, \beta \in [0, 1]$, let α = β = 0.5, S_i^+ integrally reflects the degree of association of the *i* evaluation object with the positive ideal solution, the larger the value, the better the evaluation result. S_i^- is the opposite.

Step 9: Calculate the closeness of each object to the positive ideal solution.

The closeness indicates the closeness of the evaluation target to the optimal target for each city's rural area, and the value range is [0,1]. The larger the value is, the closer the sustainability level of the area is to the optimal level, so the result can be used to rank the sustainability of the rural human settlement environment. The calculation formula is as follows.

$$c_i^+ = \frac{S_i^+}{S_i^- + S_i^+}, \ (1 \le \mathrm{i} \le \mathrm{m}) \tag{24}$$

4. Empirical research

4.1. Study sample area and data acquisition

In order to continuously improve the sense of access, happiness, security, and identity of rural villagers, the Chinese government is gradually promoting the construction of shared prosperity demonstration zones. Zhejiang Province has become the first shared prosperity demonstration zone in China, whose core objective is to solve the disparity between urban and rural areas. The Key to narrowing the disparity between urban and rural areas lies in the sustainability of the human living environment. Therefore, this paper evaluates the sustainability of the rural areas of 11 prefecture-level cities in Zhejiang Province. There are 11 cities and 90 counties (cities and districts) in Zhejiang Province. Twenty-six mountainous and island counties are among the 90 districts and counties, accounting for 45% of the land area and 24% of the population of Zhejiang but only 9.65% of the total GDP. In this paper, the habitat environment of the villages in 11 prefecture-level cities is taken as the object of study because: (1) these 11 prefecture-level cities contain all the geographical areas of Zhejiang Province. (2) The urban sustainability of the prefecture-level cities in Zhejiang Province is more vital, and the sustainability of the rural areas is weaker compared to the rural areas, which are the Key to achieving the goal of shared prosperity. (3) As a demonstration area of shared prosperity, Zhejiang Province has a better development of its rural economic level. At the same time, Zhejiang has a general geographical environment with strong replicability so that other regions can refer to the sustainable development of human habitat in rural areas of Zhejiang Province. Zhejiang has a particular guiding significance.

According to the evaluation index system in Table 1, the sustainability of the habitat environment in rural Zhejiang Province is evaluated through field research and visits to relevant government departments. The data of some indicators in the index system are sourced from *the China Rural Statistical Yearbook in 2021*, *the China Urban, and Rural Construction Statistical Yearbook in 2021*, *the Zhejiang Provincial Statistical Yearbook in 2021*, *the statistical yearbooks of prefecture-level cities in 2021*, and the Department of Agriculture and Rural Affairs of Zhejiang Province, and other statistical data are compiled through the data to finally arrive at the index data of the rural areas of 11 prefecture-level cities. As shown in Tables 2a and 2b.

4.2. Numerical calculation

Calculating the weight of each indicator. According to equations (1)–(4), a multidimensional decision matrix is established by the relevant SDGs-related indicators, normalized and normalized. Meanwhile, the information entropy value e_j, information utility value d_j, and weight w_j are calculated by Eqs. (5)–(7). As shown in Table 3.

Calculation of positive and negative ideal solutions. According to equations (8) and (9), the decision matrix is normalized, and the weighted decision evaluation matrix is also processed. According to equations (10) and (11), each index's positive and negative ideal solutions are calculated. As shown in Table 4.

They calculated the distance between sustainability and positive and negative ideal solution scenarios for the study sample areas. Based on equations (12) and (13), the distances of sustainability from positive and negative ideal solutions were calculated for each study sample area. As shown in Table 5.

Calculating the grey correlation degree of each study sample area. According to equations 14–17, the grey correlation degree of

Table 2
aRural human settlement environment sustainability evaluation data of prefecture-level cities in Zhejiang Province (I).

Code	Hangzhou	Ningbo	Wenzhou	Jiaxing	Huzhou	Shaoxing
B1	15,703	12,662	4510	8183	9449	15,244
B2	333	356	164	132	149	227
B3	501.53	554.58	260.65	221.73	252.84	339.79
B4	2152.09	2846.48	3151.55	3873.35	3828.35	3626.24
B5	157.01	175.53	117.62	167.38	135	154.92
B6	42,692	42,946	35,844	43,598	41,303	42,636
B7	1.75	1.72	1.94	1.6	1.65	1.71
B8	29.58	30.62	29.39	29.1	29.4	29.99
B9	81.2	83.2	81.6	72.2	78.2	78.5
B10	30,224	27,451	25,198	24,482	27,134	27,471
B11	2458	1682	1328	1902	2095	1880
B12	9.87	9.07	8.69	4.65	6.04	6.93
B13	270.9	226	254	283	296	263
B14	75.5	58.24	59.7	73.46	68.5	68.7
B15	3737	3146	2793	2079	2143	2040
B16	99.85	99.8	99.94	100	100	100
B17	79,755	84,456	70,270	80,363	36,648	73,043
B18	5147.87	4271.04	3077.5	4132.34	2450.76	4401.53
B19	87.9	95.9	98.9	90.1	84.4	93.4
B20	66.85	48	61.9	12.74	48.4	55.18

Table 2b
Rural human settlement environment Sustainability Evaluation Data for Prefectural Cities in Zhejiang Province (II).

Code	Jinhua	Quzhou	Zhoushan	Taizhou	Lishui
B1	7372	7646	3332	7346	11,336
B2	150	87	159	304	108
B3	248.83	141.18	285.55	542.71	159.1
B4	2603.99	3226.60	1873.11	2748.85	3038.92
B5	170	104.75	14.56	124.69	97.01
B6	33,709	29,266	42,945	35,419	26,386
B7	2.03	1.86	1.61	1.94	2.05
B8	29.06	29.03	29.09	29.02	29.01
B9	80.6	79.2	70.4	83.6	72.1
B10	20,112	17,872	27,831	23,001	21,613
B11	2289	2264	2257	1675	1599
B12	9.32	9.95	4.14	9.59	8.07
B13	231.7	255.2	223	248	248
B14	61.2	81.3	56.47	58.8	67.1
B15	1825	1572	1316	2041	1338
B16	99.65	100	99.8	99.95	100
B17	75,054	52,524	3962	77,443	49,119
B18	3741.76	2263.99	344.12	2600.43	2131.25
B19	95.1	95.6	98.1	99.2	99.7
B20	61.86	71.5	50.66	61.46	81.7

Table 3
The weight of each index using the entropy method.

Code	e_j	w_j
B1	0.90579	0.04517
B2	0.86679	0.063869
B3	0.867446	0.063554
B4	0.923661	0.036602
B5	0.953475	0.022307
B6	0.928661	0.034204
B7	0.893764	0.050936
B8	0.727063	0.130862
B9	0.912967	0.041729
B10	0.928764	0.034155
B11	0.925976	0.035492
B12	0.918578	0.039039
B13	0.886915	0.05422
B14	0.86426	0.065082
B15	0.856787	0.068665
B16	0.944914	0.026411
B17	0.811019	0.090609
B18	0.907052	0.044565
B19	0.936058	0.030658
B20	0.954383	0.021871

each study sample area was calculated. As shown in Table 6. According to equations 18–21, the dimensionless processing index was performed. As shown in Table 7.

They calculated the relative proximity and ranking of each study sample area. According to Equations 22–24, each study sample area's relative proximity and ranking were calculated.

4.3. Analysis of evaluation results

Fig. 1 is drawn based on the results in Table 8. From a regional perspective, the overall sustainability of the rural human settlement environment in northern Zhejiang is more vital than that in central and western Zhejiang. In terms of cities, Hangzhou has the highest level of sustainability in the rural human settlement environment in Zhejiang Province, followed by Ningbo with the second highest level of sustainability and Zhoushan with the lowest. Hangzhou has made better development in recent years in constructing beautiful countryside, socialized agricultural services, digital governance of the countryside, and quality public services. Its final sustainability score is significantly higher than that of other rural areas.

The rankings in northern Zhejiang are Hangzhou first with 0.6822, Jiaxing fifth with 0.5058, and Huzhou eighth with 0.4517. The sustainability level of the rural areas in the whole northern Zhejiang region is relatively strong. Hangzhou, the capital of Zhejiang Province, is the "leader" of the rural revitalization program in Zhejiang Province. Hangzhou's rural human settlement environment ranks high in all indicators, mainly due to the following programs. In terms of the production environment, in recent years, efforts have

Table 4
Positive and negative ideal solutions for each index.

Code	x^+	x^-
B1	0.0212	0.0045
B2	0.0317	0.0077
B3	0.0305	0.0078
B4	0.0140	0.0068
B5	0.0087	0.0007
B6	0.0117	0.0071
B7	0.0174	0.0136
B8	0.0411	0.0389
B9	0.0134	0.0113
B10	0.0124	0.0074
B11	0.0133	0.0072
B12	0.0145	0.0060
B13	0.0189	0.0143
B14	0.0239	0.0166
B15	0.0336	0.0118
B16	0.0080	0.0079
B17	0.0348	0.0016
B18	0.0203	0.0014
B19	0.0098	0.0083
B20	0.0092	0.0014

Table 5
The distance between sustainability and positive and negative ideal solutions in rural areas of each city.

City	d_i^+	d_i^-
Hangzhou	0.0086	0.0570
Ningbo	0.0134	0.0552
Wenzhou	0.0328	0.0359
Jiaxing	0.0352	0.0391
Huzhou	0.0385	0.0252
Shaoxing	0.0246	0.0429
Jinhua	0.0346	0.0369
Quzhou	0.0443	0.0273
Zhoushan	0.0551	0.0136
Taizhou	0.0247	0.0457
Lishui	0.0440	0.0260

Table 6
The degree of grey correlation for rural areas in each city.

City	q_i^+	q_i^-
Hangzhou	0.9359	0.7160
Ningbo	0.8998	0.7431
Wenzhou	0.8008	0.8042
Jiaxing	0.8116	0.8118
Huzhou	0.7946	0.8026
Shaoxing	0.8502	0.7584
Jinhua	0.8092	0.8039
Quzhou	0.7899	0.8370
Zhoushan	0.7268	0.9232
Taizhou	0.8385	0.7787
Lishui	0.7739	0.8468

been made to improve the level of agricultural marketization, scale, mechanization, modernization, and internationalization, and to develop high-quality and high-efficiency agriculture such as urban agriculture, order agriculture, leisure experience agriculture, and biological agriculture, to build a new system of modern industry in the countryside. Implement the construction of digital countryside, and build several digital agricultural factories and digital breeding bases. In terms of the living environment, measures such as narrowing the income gap between urban and rural residents, organizing high-quality kindergartens, encouraging municipal high-quality high schools to build branch schools in districts, counties, and cities, ensuring complete coverage of tertiary hospitals and public elderly institutions, and promoting 5G network coverage.

Regarding the ecological environment, Hangzhou focuses on sewage treatment, garbage classification, and the construction of

Table 7
Dimensionless processing.

City	D_i^+	D_i^-	Q_i^+	Q_i^-
Hangzhou	0.1561	1.0000	1.0000	0.7756
Ningbo	0.2433	0.9698	0.9614	0.8049
Wenzhou	0.5947	0.6299	0.8557	0.8711
Jiaxing	0.6387	0.6863	0.8672	0.8793
Huzhou	0.6980	0.4424	0.8490	0.8693
Shaoxing	0.4462	0.7524	0.9085	0.8215
Jinhua	0.6273	0.6472	0.8646	0.8708
Quzhou	0.8043	0.4799	0.8440	0.9067
Zhoushan	1.0000	0.2393	0.7766	1.0000
Taizhou	0.4482	0.8028	0.8959	0.8435
Lishui	0.7984	0.4569	0.8269	0.9172

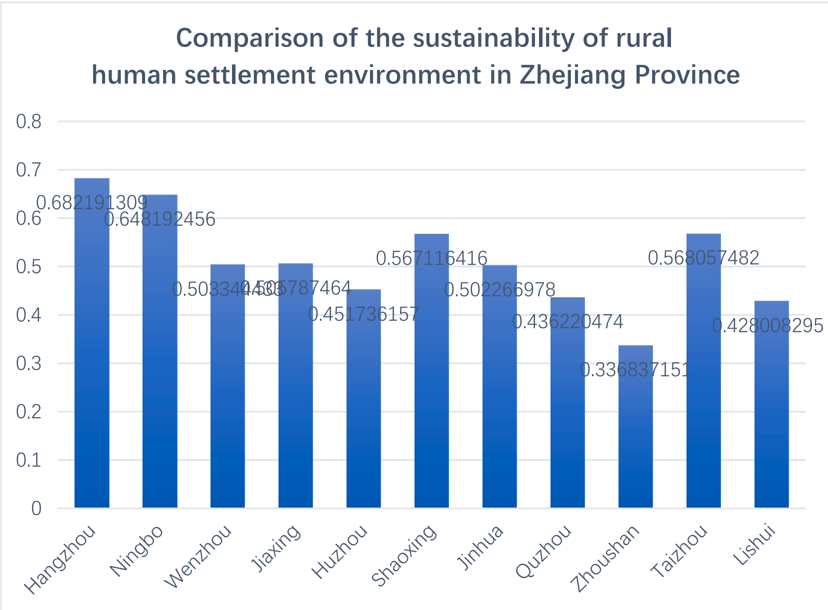

Fig. 1. Comparison of the sustainability of rural human settlement environment in Zhejiang Province.

Table 8
The relative closeness and ranking of cities.

City	S_i^+	S_i^-	c_i^+	Rank
Hangzhou	1.0000	0.4659	0.682191309	1
Ningbo	0.9656	0.5241	0.648192456	2
Wenzhou	0.7428	0.7329	0.503344433	6
Jiaxing	0.7768	0.7590	0.505787464	5
Huzhou	0.6457	0.7837	0.451736157	8
Shaoxing	0.8304	0.6339	0.567116416	4
Jinhua	0.7559	0.7491	0.502266978	7
Quzhou	0.6619	0.8555	0.436220474	9
Zhoushan	0.5079	1.0000	0.336837151	11
Taizhou	0.8494	0.6458	0.568057482	3
Lishui	0.6419	0.8578	0.428008295	10

environmentally friendly toilets. Jiaxing is in the middle to the upper level of Zhejiang Province. The main areas for improvement are the lack of agricultural land and the integration of modern agricultural industry with secondary and tertiary industries. Huzhou is a rural area with relatively weak sustainability in northern Zhejiang Province. The main areas for improvement are insufficient rural planning, sloppy industrial development methods, and lack of scientific and technological support for production methods.

The rankings in eastern Zhejiang are Ningbo second with 0.6482 points, Shaoxing fourth with 0.5671 points, and Zhoushan eleventh with 0.3368 points. There is a wide gap in the sustainability level of the rural areas in the whole eastern Zhejiang region. As a sub-provincial central city in Zhejiang Province, Ningbo has the top sustainable level in the countryside. Ningbo's rural human settlement environment ranks high in all indicators and is analyzed as follows. Regarding the production environment, Ningbo has a high level of agricultural modernization, ranking among the top in the province, and has also become a national modern agricultural demonstration area. The level of agricultural mechanization is leading in the province, with a total mechanization rate of 90% for cultivation, seeding, and harvesting of significant crops; the level of sustainable agricultural development is high. In terms of the living environment, farmers' income is high. It continues to grow balanced, the income gap between urban and rural areas is small, and social undertakings such as education, medical care, culture, and sports are developing at an accelerated pace. In the ecological environment, rural domestic sewage treatment, rural public toilets, and rural domestic garbage classification all achieve full coverage of the established villages. However, Ningbo still uses more pesticides and fertilizers, and the green production level needs further improvement. Shaoxing in the entire Zhejiang Province at the upper level, in the ecological environment, needs to be further improved. Zhoushan is located in coastal areas, and there are more apparent areas for improvement in the production environment and living environment. The richness of rural industrial forms and industrial development layout in the production environment needs to be increased due to geographical reasons. The lack of rural infrastructure and technical personnel is crucial in enhancing rural areas' sustainability in the living environment.

The rankings in southern Zhejiang are Taizhou third with 0.5681, Wenzhou sixth with 0.5033, and Lishui tenth with 0.4280. There is a wide gap in the sustainability level of the rural areas in the whole southern Zhejiang region. Taizhou has high scores in the production environment and ecological environment. Still, in the living environment, policymakers need to develop measures to improve the quality of the population, the quality of the living environment, and social welfare, in addition to further strengthening investment in education and culture. Wenzhou's rural human settlement environment sustainability is at the middle level of Zhejiang Province; Lishui is at a more backward level of the province. In terms of the production environment, it is necessary to promote rural economic growth further and enhance the level of agricultural modernization; in terms of the living environment, it is also necessary to further improve infrastructure construction and medical and educational levels; in terms of ecological environment, the ecological environment in southern Zhejiang is better, and it is necessary to further focus on rural environmental awareness to promote environmental sustainability.

The important rankings in central and western Zhejiang are Jinhua 7th with 0.5023 points and Quzhou 10th with 0.4362 points. Both cities are far from the coast, industrial development is somewhat restricted, and the per capita income level needs further improvement. However, the ecological environment construction in central and western Zhejiang is among the top levels in the province. Quzhou's Future Countryside Program has become a national model project. Since 2020, Quzhou has launched various future countryside, contiguous development models, such as agriculture-based, ecological, cultural, and commercial, and Quzhou's countryside will have further development. Its sustainable level will be further improved in the coming years.

5. Discussion and recommendations

5.1. Discussion

Rural human settlement environment sustainability is a complex dynamic system influenced by various indicators and development trends. However, factors such as subjectivity in determining the weights of indicators and uncertainty in the evaluation process should be addressed in traditional rural sustainability studies. At the same time, since most contemporary sustainability theories are centered on urban studies, there are fewer studies evaluating rural sustainability. Therefore, this paper proposes an improved method for evaluating the sustainability of rural human settlement environments and ranking the sustainability level of rural human settlement environments. The main contributions of this paper can be summarized as follows: (1) Based on the existing theories of rural revitalization and rural sustainability, a set of high-quality rural sustainability evaluation research systems that combines production, living and ecological environment in line with the goal of sustainable development is established. (2)To propose an improved method for evaluating the rural habitat environment. This paper couples the TOPSIS method with the Grey relational analysis method and uses the entropy weight method for weight calculation to form a multi-integrated evaluation model of the sustainability of rural human settlement environment based on the combination of the entropy weight TOPSIS and the Grey relational analysis method. The model starts from the data itself, eliminating the subjectivity of experts' scoring, and the evaluation results of the model are consistent with the actual research results, indicating that the evaluation results obtained by this method have strong credibility. The model not only avoids the shortcomings of the traditional weighted TOPSIS method, which cannot judge the trend of internal factors, but also can make a reasonable and practical judgment on the overall sustainability level of rural human settlement environment, and at the same time can calculate the ranking of different levels of indicators by the entropy weighting method. The evaluation results show that the sustainability of the habitat environment in rural areas of Zhejiang Province is significantly lower than that in urban areas, which is consistent with the implementation of the rural revitalization project and related policies to promote the economic, social, and ecological development of rural areas in China.

There are differences in rural habitat between cities in Zhejiang Province, but scientific decisions are conducive to promoting rural economic growth and sustainable rural development. First, there is a correlation between the level of rural sustainability between regions and the economic level of that city. According to the latest data of the *Zhejiang Province Statistical Yearbook 2021*, the ranking of the province's GDP is Hangzhou, Ningbo, Wenzhou, Shaoxing, Jiaxing, Taizhou, Jinhua, Huzhou, Quzhou, Lishui, and Zhoushan, which has a high similarity with the ranking of this study. Therefore, the economic level affects the sustainability level of the rural human settlement environment to a certain extent. Second, scientific decision-making promotes sustainable rural development. The "Rural Future Communities" program implemented by Zhejiang Province in recent years is conducive to the sustainable development of rural areas. A future rural community is a new rural community form and a humanistic integration platform of production and village with "sustainable development" as the guide, "future-oriented" as the feature, and "high quality of life" as the center. It is also a new model to promote the high-quality development of rural revitalization with the dimension of community construction.

Geographical location is an essential factor affecting sustainable rural development. In terms of geographical division, the sustainable level of rural areas in Zhejiang province shows that all three regions (northern Zhejiang, eastern Zhejiang, and southern Zhejiang) have cities with better sustainable development (Hangzhou, Ningbo, and Taizhou), reflecting better economic growth and infrastructure; the sustainable level of rural areas in central and western Zhejiang needs to be further strengthened, reflecting the need further to strengthen economic development, infrastructure, and environmental improvement. After Zhoushan became independent from Ningbo, there were still significant areas for improvement in various aspects of the human environment, especially in industry. In summary, the development trend of the countryside is related to its location, with the overall level of rural sustainability in the coastal areas being better than in the rural areas of the western mountainous regions.

The following limitations exist in this study. First, due to the limitation of data in the statistical yearbook, the research unit of this paper is rural, and there are differences in the sustainability development of habitat within the unit for rural areas with more extensive areas. The research unit can be improved to improve the study's accuracy. Secondly, in terms of quantitative data collected nationally and locally, there are significant differences in the indicator data collected by each city. The lack of data in some cities leads to an indicator evaluation system that only comprehensively covers some factors of sustainability evaluation. A sustainability indicator evaluation system for rural human settlement environments that contains a combination of quantitative and qualitative primary data sets can be established in future studies.

5.2. Policy recommendations

Based on the evaluation results of this paper, the following policy recommendations are proposed as a way to improve the sustainability of rural areas in different regions. (1) The production environment is the Key to sustainable rural development. The overall sustainable production environment in the rural areas of central and western Zhejiang needs to be stronger. Therefore, it is necessary to increase financial investment in some areas to balance the sustainable level of the economy between regions. The governments of rural areas with irrational development should increase financial investment, which can be used to boost economic growth through a series of rural preferential policies, financial transfer payments, and tax relief policies. Second, inter-regional helping policies can be formed. Rural areas with good sustainability, such as cities like Hangzhou and Ningbo, can help cities like Lishui and Zhoushan, which could be more sustainable, to achieve overall sustainable development. (2) The construction of the living environment is essential in ensuring sustainable development in rural areas. It is necessary to strengthen the construction of people's livelihoods further and promote a sustainable inter-regional society. Indicators such as the per capita disposable income of rural households, the ratio of per capita disposable income of urban and rural residents, the average number of village health rooms per 10,000 people, the average number of cell phones per 100 households, and the percentage of towns and cities with places for the elderly constitute common development obstacles faced by rural areas. Therefore, it is necessary to increase the investment in the modernization of medical care, education, and elderly care, improve infrastructure construction, and improve the social sustainability of rural areas. (3) The ecological environment construction in western Zhejiang is better than in other regions. Therefore, western Zhejiang continues to seize the advantages, turn the ecological environment advantages into economic growth, and further promote green development in rural areas. The regions of eastern Zhejiang, northern Zhejiang, and southern Zhejiang should vigorously strengthen the construction of the ecological environment and comprehensively promote the green development of rural areas. First, each region should make full use of the advantages of natural conditions, not destroy the original environment, strengthen the accessibility of rural forests, and build model villages with high standards of livability; second, pay attention to carbon emissions while developing the economy, use clean energy reasonably, and protect the atmosphere. Standardize pesticides and fertilizers, strengthen the management of waste classification and public toilets in rural areas, and conserve water resources.

6. Conclusion

In this study, a 20-indicator system based on three dimensions: production environment, living environment, and the ecological environment was constructed to evaluate the sustainability of the rural human settlement environment in 11 prefecture-level cities in Zhejiang Province, and an improved TOPSIS based on Grey relational analysis was proposed to assess rural sustainability. The framework of this evaluation system helps quantify the sustainability of the rural human settlement environment. It can also provide suggestions and guidance for local governments to formulate policies.

The results show that the overall sustainability level of the rural human settlement environment in Zhejiang Province is good, and the overall level and coordination of the ecological environment is better than that of the production and living environment. At the level of the production environment, the overall sustainability level is better in northern Zhejiang, followed by eastern and southern Zhejiang, and the overall sustainability level is weaker in central and western Zhejiang. The primary industry's total output value, agriculture, forestry, animal husbandry, fishery, and food productivity are important factors for improving rural sustainability. At the ecological environment level, the sustainability of western Zhejiang is due to other regions. For example, the rate of good ambient air quality and forest coverage. In terms of the living environment, indicators such as per capita disposable income of rural households, the ratio of per capita disposable income of urban and rural residents, the average number of village health rooms per 10,000 people, the average number of cell phones per 100 households, and the percentage of towns and cities with elderly care places are common factors limiting the sustainable development of these regions.

Due to the limited measurement dimensions and availability of raw data, the comprehensiveness of the covered dimensions of this study still needs to be improved. In future studies, the data types can be further expanded, and the interplay of the development of rural production, living and ecological environment needs to be considered to address possible biases in the assessment process to improve the evaluation system of rural human settlement environment sustainability indicators.

Author contribution statement

ShuaiJun Lin: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.
LiDan Hou: Performed the experiments; Contributed reagents, materials, analysis tools or data.

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Declaration of interest's statement

The authors declare no conflicts of interest.

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