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Examining the links between household livelihood resilience and vulnerability: disaster resettlement experience from rural China

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Livelihood status of rural households is the focus of disaster resettlement research. Influenced by various factors, rural households face multiple environmental and social pressures after relocation, and the study of livelihood resilience and vulnerability provides a new framework for research into the livelihoods of relocated households. There has been a call for more quantitative evidence about the links between livelihood resilience and livelihood vulnerability in the context of disaster resettlement. This study uses data from a sample of 657 individuals from the relocation area of Ankang prefecture in southern Shaanxi, China. The resilience of rural household livelihood systems is quantified in terms of two dimensions of general resilience and specific resilience using the spatial vector method from systems engineering. The IPCC framework was used to measure three dimensions of livelihood vulnerability: exposure, sensitivity, and adaptability, and a threshold regression model was applied to investigate the impacts of livelihood resilience on livelihood vulnerability. Results show that: (i) livelihood vulnerability of relocated households (−0.042) was significantly lower than that of local households (0.091), while relocated households in the process of livelihood reconstruction had a certain degree of vulnerability risk. (ii) there is a significant threshold effect of livelihood resilience on livelihood vulnerability of rural households. (iii) increasing livelihood resilience significantly reduced the degree of vulnerability of rural households, and the marginal effect of general resilience on livelihood vulnerability shows a decreasing trend. Specific resilience has a positive influence on livelihood vulnerability before it exceeds the threshold, but the effect disappears above the threshold of resilience. (iv) The threshold value of livelihood resilience of local households (0.5039) is generally lower than that of relocated households (0.6548), and relocation does improve the ability of rural households to resist uncertainty risks. It is necessary for local governments to formulate more targeted policies to reduce the livelihood vulnerability of rural households and thereby promote sustainable livelihood development.

KEYWORDS

disaster resettlement, livelihood resilience, livelihood vulnerability, rural households, China

1 Introduction

Disaster resettlement is a tactic for alleviation of suffering for those who cannot reside in their original communities because of widespread hazards (Xu et al., 2022). Previous studies on disaster resettlement have mostly focused on climate-change-induced relocations such as floods (Kita, 2017), earthquakes (Bahadur, 2021) or tsunamis (Weerasena et al., 2018), or development-induced relocations such as the construction of dams and hydro power projects (Reddy, 2018; Mavhura, 2020). Although there has been considerable literature about the ecological (Chen and Tsai, 2021) and demographic (Lo and Wang, 2018) aspects of disaster resettlement, less is known about how to accomplish livelihood reconstruction in the case of disaster resettlement. Indeed, livelihood is a major challenge for resettlement projects and is a meaningful and necessary perspective for exploring the impacts of disaster-related resettlement. This article expands on previous research on disaster resettlement by studying the relationship between livelihood resilience and livelihood vulnerability at the household level in rural resettlement areas of China. The concepts of resilience and vulnerability are intertwined (Gallopín, 2006). However, they have often been used separately to analyze livelihood responses to perturbations (Eadie et al., 2020; Sunil et al., 2023), or to construct a framework including both, while still studying the impact of external changes separately (Nath et al., 2020; Tina et al., 2022). Importantly, the livelihood resilience and vulnerability of rural households have received less attention in the disaster resettlement context, especially in terms of analyzing the linkages between them. This paper focuses on the interactions between household livelihood resilience and livelihood vulnerability that might assist in local policymaking towards sustainable development.

The concept of resilience has its origins in ecological science as the ability of a system to maintain its original state when faced with change (Holling, 1973). Resilience has been a focus of study in many disciplines over recent decades (Walsh-Dilley et al., 2016). Much of this research has focused on natural sciences such as ecology and engineering (Brown, 2014), ignoring the political or social aspects (Quandt, 2018). In response to these neglects, livelihood is proposed as a new lens (Liu et al., 2020). Livelihood resilience is defined as the ability of an individual or household to cope with stresses or disturbances caused by environmental changes and to recover from their adverse impacts (Speranza et al., 2014). Empirical studies on this topic have found that the factors influencing livelihood resilience vary among regions in different geographical (Sun et al., 2023) and climatic contexts (Kumar et al., 2020), and in ecological settings (Rabiul and Greg, 2022). For example, coastal residents in Bangladesh have suffered severe damage to their livelihoods and assets due to cyclones (Salim et al., 2021). Prolonged drought has caused long-term damage to agricultural production in northern Ghana, severely reducing the resilience of livelihoods of local residents (Asante et al., 2021). These studies highlighted the critical role of social networks (Antonio et al., 2022), government documents (Daniel et al., 2019) and individual wellbeing (Dantje et al., 2019) in livelihood resilience assessment. Using synthetic evaluation (Liu et al., 2020), scenario simulation (Maksims and Francesco, 2021) and other methods to measure resilience, the study of resilience has shifted from temporal to spatial (Li et al., 2021a). This paper introduces the spatial vector approach of system dynamics to measure livelihood resilience, incorporating livelihood characteristics of rural households.

In the context of sustainable development, livelihood resilience is often connected to livelihood vulnerability. It is described as "the degree to which households are exposed to or unable to cope with natural, social, political, and economic pressures" (Zhang et al., 2022a). Vulnerability also has the meaning of "being open to harm or damage" (Taleb, 2014). Scholars have gradually turned to assessing livelihood vulnerability at the household level. Three main analytical frameworks have been proposed: (i) The Sustainable Livelihood Approach (SLA) proposed by the Department for International Development (DFID) in the United Kingdom, which explains the processes and mechanisms of livelihood vulnerability (Bhattacharjee and Behera, 2018). (ii) The exposure–sensitivity–adaptability analytical framework proposed by Polsky (Polsky et al., 2007) is used to assess the level of vulnerability. (iii) A comprehensive livelihood vulnerability analysis framework developed by Reed to examine vulnerability to climate change (Reed et al., 2013). The "Exposure-Sensitivity-Adaptive Capacity" framework has been empirically tested in different regions and contexts such as India (Pankaj and Swades, 2022), Vietnam (Duc et al., 2022) and China (Huang et al., 2017; Zhang et al., 2018; Peng et al., 2018). For example, Reddy et al. built a multidimensional farmer distress index from a seven-dimensional study of risk exposure, adaptive capacity and sensitivity. It provides a reference for the sustainability and vulnerability of rural households' livelihoods (Reddy et al., 2021). Here, we adopt this framework to quantify and calculate livelihood vulnerability.

We make the following two innovations: (i) we quantify and measure livelihood resilience based on the level of income of rural households and the type of livelihood activity rather than the traditional livelihood capital or the three major capabilities. At the same time, the spatial vector method in system dynamics is introduced into the calculation of livelihood resilience, which enriches the livelihood research methodology. (ii) We link livelihood resilience to livelihood vulnerability and explore the relationship between the two using a threshold regression approach in the hope that new contributions can be made. We first present the relevant concepts and then describe our data and methodology. We calculate livelihood resilience and livelihood vulnerability separately and explore the relationship between the two using a threshold regression model to find the threshold of resilience. Finally, we discuss our findings and summarize our conclusions.

2 Data and methods

2.1 Data source

The data for this article were obtained from a special survey on household livelihoods conducted in Ankang prefecture, southern Shaanxi, China (Figure 1). Our data came from the rural household survey conducted by the research group of the Population and Development Institute of Xi'an Jiaotong University in Ankang in 2015. The investigators were teachers, graduate students, and undergraduates from Xi'an Jiaotong University, Northwest University, and Xi'an University of Finance and Economics. Ankang is in southern Shaanxi, China, the hin-terland of the Qinling Mountains in the upper reaches of the Han River, and has always been a disaster-prone area. Disaster prevention and mitigation has been a priority for the local government. In 2011, the government of Shaanxi province launched a disaster resettlement program (Liu et al., 2020;

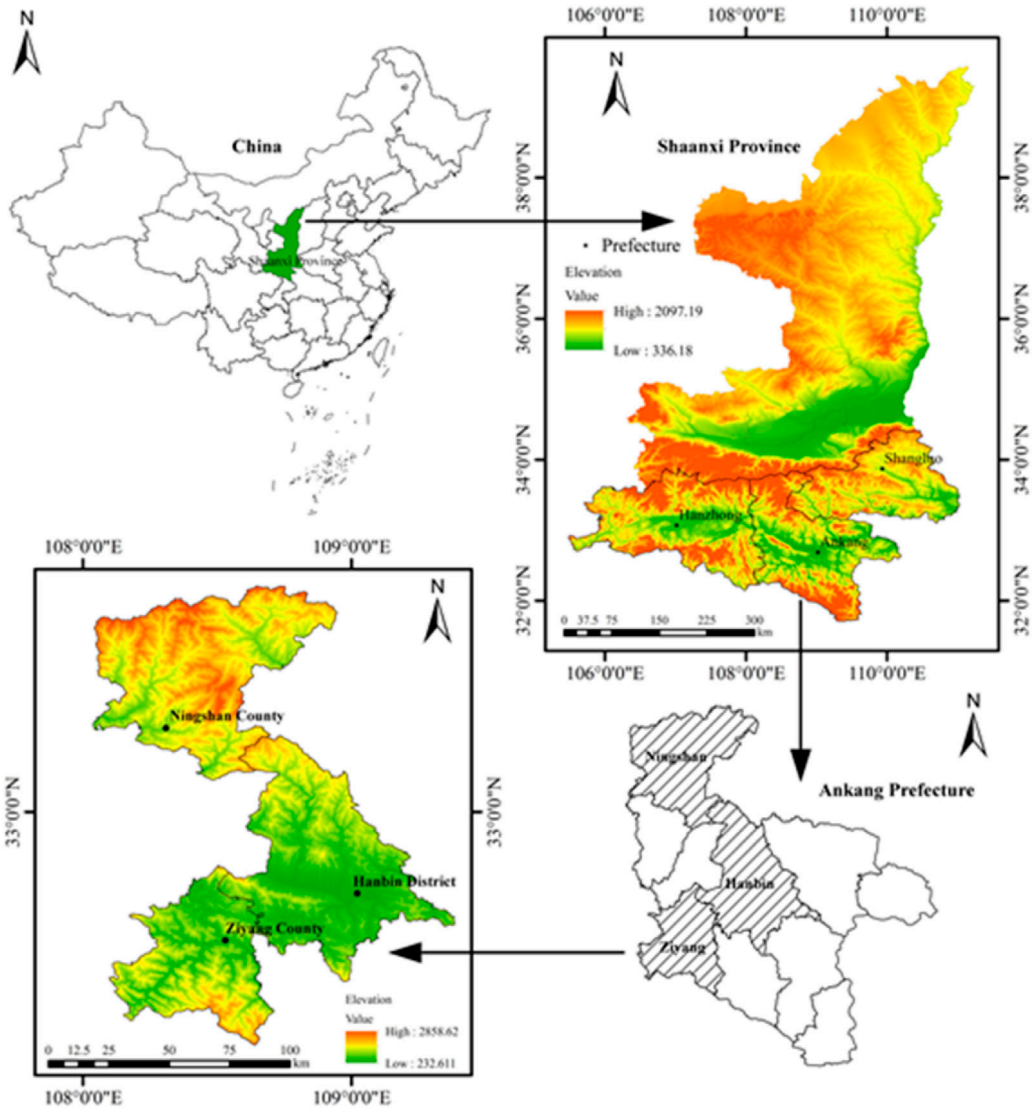

FIGURE 1
Location of the study area (Liu et al., 2020).

Liu et al., 2022), whose aim was to help rural poor people in remote areas to re-locate to new settlement communities. Since the plan began, Ankang prefecture has moved 267,300 households, or 937,800 people, accounting for 39.7% of the total number of people moved in the province (Liu et al., 2020b). The plan faces great difficulties in local economic and social development as a disaster-prone, poverty-ridden, and ecologically important area. The present survey adopted convenience sampling for some administrative villages or resettlement communities, and randomly selected household members between the ages of 18 and 65 for interviews or other permanent residents who met the age requirement. Based on the representativeness and feasibility of sample selection, we conducted research in Ziyang County, Hanbin District, and Ningshan County. Considering ecological conditions, transportation availability, and types of migrant resettlement in the surveyed areas, three typical centralized resettlement communities were first selected in Ziyang county. Eight administrative villages in four towns in other two places where ecological compensation projects, such as returning farmland to forests, were implemented were also included in the sample frame. The contents of the survey included demographic characteristics, consumption behavior of rural households, and information related to relocation. A total of 657 valid questionnaires were obtained, of which 69.7% were from relocated households and 30.3% were from local households.

2.2 Selection of variables

2.2.1 Livelihood resilience

Livelihood resilience is the ability of rural households to withstand disturbances and recover from adverse outcomes through a combination of livelihood activities. Specific resilience entails coping with a specific disturbance, while general resilience involves coping with different types of disturbances and shocks. Drawing on the spatial vector method proposed by Li et al. (2021a), the livelihood resilience of rural households was measured according

to two dimensions: general resilience and specific resilience, based on the livelihood activities of rural households. The specific measurement steps are as follows:

(1) To simplify the livelihood system of rural households by observing livelihood activities, a quantitative model of rural households' livelihood level, R, can be characterized by the following relational expressions:

$$R\ (K) \Rightarrow N$$
$$A = \{M_1, M_2, \ldots, M_N\}, S = N$$
$$A_S = \{M_1, M_2, \ldots, M_N\} \subseteq A, S \leq N$$

Where K is a classification standard for livelihood activities, meaning rural household income; N is the number of all livelihood activities of rural households. A is a classified collection of livelihood activities; S is the number of livelihood activities engaged in by a rural household; A_S is a set of livelihood activities for a rural household, which is a subset of set A; M_i is the *i*th livelihood activity, namely the *i*th income source for the rural household ($1 \leq i \leq S$), When S = N, the set A_S of a rural household engaged in livelihood activities is the full set A. The level of livelihood diversification of rural households can be expressed as (N, S, A). According to the reality of the livelihood activities of rural households in the study area, the livelihood activities of rural households include agricultural and forestry activities, breeding activities, working activities and non-agricultural business activities including agri-tourism and transportation. Then the following formula can be obtained:

$$R\ (K) \Rightarrow N = 4$$

A = {Agriculture and forestry activities, breeding activities, working activities, non-agricultural business activities}, S = N.

$A_S \subseteq A$, $S \leq 4$, and have C_4^s sets of A_S

(2) Universal resilience measure, Fa. Using the level of livelihood diversity (N, S, A) as a reference system to describe the stability of income, the ratio of the rural household's income to the maximum income value in the corresponding set A_S is estimated, and when this ratio is small it indicates that the rural household's income is less stable, and for a rural household with a level of livelihood diversity (N, S, A) and a total income of M, there exists a maximum income M_A in set A. The formula for the general elasticity of this rural household is:

$$F_a = M/M_A \tag{1}$$

(3) Specific resilience measure, Fv. The rural household is engaged in N classifications under the set of A_S livelihood activities containing S classifications {M_1, M_2, . . . , M_S }, the *i*th livelihood activity income is m_i (i = 1, 2, . . . , S) and the total is M. The probability of having any yuan income belonging to A_i (i = 1, 2, . . . , S) is P_i, thus $P_i = m_i/M$ with $\Sigma P_i = 1$. Using the Shannon-Wiener calculation, the livelihood diversity index of this rural household was:

$$D_m = -\sum_{i=1}^{s} P_i \ln P_i \tag{2}$$

For the livelihood diversity index D_m corresponding to a rural household's livelihood diversity level (N, S, A), the maximum value is $\ln_S$, and the value of specific resilience F_v is calculated as:

$$F_v = D_m / \ln s \tag{3}$$

Greater specific resilience indicates that rural households have multiple sources of income and that income is more evenly distributed, and when external shocks lead to a severe reduction of a certain income, they do not cause large fluctuations in rural household income and consumption levels, and the rural household livelihood system is able to operate stably. Referring to the common practice of system prediction and decision making, universal and specific resilience were defined as vectors (Figure 2), the angle of the vectors was calculated by cosine similarity, and the livelihood resilience of the rural households was estimated based on the cosine theorem. Measure the magnitude of α value using Eqs. (1) and (3) is:

$$\cos\alpha = \langle F_a, F_v \rangle / |F_a||F_v| \tag{4}$$

Cos α is determined with the help of Pearson's correlation coefficient, which eliminates the effect of magnitude and allows

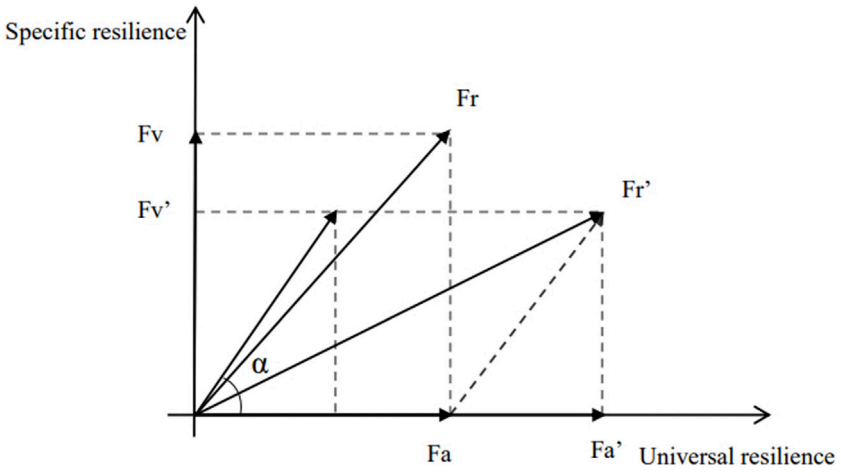

FIGURE 2
Measurement of livelihood resilience.

TABLE 1 Data for the index of livelihood vulnerability.

Dimensions	Evaluation Indices	Definition (Unit)	Mean	SD
Exposure	Agroforestry shock	Actual amount of annual agricultural and forestry losses (yuan)	75.367	858.024
	Property shock	Amount of actual loss of property for the year (yuan))	298.634	4809.138
	Livestock shock	Amount of actual loss of livestock for the year (yuan)	28.956	456.721
	Access to loans	1 strongly possible; 2 possible; 3 neither possible nor impossible; 4 impossible; 5 strongly impossible	0.595	0.333
Sensitivity	Labor force shock	Proportion of medical expenses to total household income (0.33 for <20%; 0.67 for 20%–50%; 1.00 for >50%)	0.565	0.228
	Income dependence	Agroforestry and livestock income as a proportion of total household income	0.198	0.272
	Food dependence	Food income as a proportion of total annual household food expenditure	0.204	0.910
	Energy dependence	Firewood collected as a percentage of annual household energy expenditure	0.184	0.283
	Availability of water resources	0 for yes; 1 for the household has no tap water	0.060	0.237
Adaptive Capacity	Household head age	Age of household head	50.642	11.703
	Work	Number of employed adult family members (persons)	0.499	0.846
	Housing structure	concrete structure is 0.33; wood structure is 0.67; civil structure is 1.00	0.429	0.218
	Farmland area	Per capita area of the cultivated land (mu/person)	0.938	1.961
	Distance to the main highway	Distance from the house to the village-level main highway (1 = 5 miles and above; 2 = 1–5 miles; 3 = below 1 mile) (1–3)	2.946	0.258
	Physical capital	Range standardization of assets owned by rural households	0.353	0.123
	Skills training	0 for non-trained household members; 1 for trained household members	0.247	0.430
	Financial help	Number of households available for assistance (persons)	0.519	1.479
	Social relationships	Number of village cadres in relatives and friends (persons)	0.067	0.089
	Agriculture income	Annual agricultural income *per capita* (yuan)	0.006	0.045
	House value	Value of the residential site (<100 thousand yuan is 1; 100–200 is 2; 201–300 is 3; >300 thousand yuan is 4)	2.659	1.034
	Housing area	Actual housing area (m^2)	4.569	1.573
	Non-agriculture income	Annual non-agricultural income *per capita* (yuan)	0.049	0.073

for a more accurate measurement of the relationship between the variables and is calculated as follows:

$$r_{av} = \sum_{i=1}^{m} (F_{ai} - \overline{F_a})(F_{vi} - \overline{F_v}) \Big/ \sqrt{\sum_{i=1}^{m} (F_{ai} - \overline{F_a})^2} \sqrt{\sum_{i=1}^{m} (F_{vi} - \overline{F_v})^2} \quad (5)$$

According to the law of cosine, the rural household's livelihood resilience is calculated.

2.2.2 Livelihood vulnerability

Following the "exposure-sensitivity-adaptability" analysis framework of the IPCC, we constructed a livelihood vulnerability evaluation index system of rural households (Table 1). Since the individual indicators are expressed in different units, we used deviation normalization to avoid problems. By means of standardized data processing, the resulting values are within (0–1). The following can be used as a suitable equation:

$$x'_{ij} = x_{ij} - x_{j\,min} \Big/ x_{j\,max} - x_{j\,min} \quad (6)$$

where x_{ij} represents the initial value of the households' indicator; x_{jmin} is the minimum of each indicator; and x_{jmax} is maximum of each indicator.

Then, we extracted the main factors determining livelihood vulnerability through principal component analysis (PCA). A total of 22 variables were subjected to principal component analysis, from which 8 principal components were identified. Using the results of principal component analysis, a formula for calculating the livelihood vulnerability index of rural households can be constructed by using the variance contribution of each principal

TABLE 2 Variables and descriptive statistics.

Variables	Meaning	Relocated (N = 424)		Non-relocated (N = 195)		All (N = 619)		Difference	
		Mean	SD	Mean	SD	Mean	SD	Mean	T
dependent variable									
LVI	Livelihood vulnerability	−0.042	0.160	0.091	0.229	0.0003	0.194	0.133	8.327***
independent variable									
Fr	Livelihood resilience	0.684	0.374	0.547	0.280	0.641	0.353	−0.137	−4.554***
Fa	Universal resilience	0.185	0.201	0.173	0.209	0.181	0.203	−0.012	−0.692
Fv	Special resilience	0.641	0.321	0.516	0.237	0.601	0.302	−0.125	−4.854***
Non-labor ratio	The proportion of non-agricultural labor force in the total number of households	0.277	0.208	0.271	0.239	0.275	0.218	−0.006	−0.300
Loan	Possibility of obtaining loans or loans	3.499	1.321	3.119	1.322	3.379	1.332	−0.380	−3.326***
Phone charge	Average household call cost *per capita*	0.542	0.889	0.500	0.604	0.529	0.810	−0.043	−0.607
Land area	Area of land	15.229	32.228	19.271	50.433	16.502	38.896	4.042	1.201

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

component as the weight by which to multiply the score value of the principal component.

$$LVI = W_1 F_1 + W_2 F_2 + \ldots + W_i F_i, \quad (7)$$

where LVI represents the score of the rural household's livelihood vulnerability; F_i is the score of the *i*th principal component; W_i is the weight of the *i*th principal component, namely, the contribution of this principal component to the overall variance; the matrix of principal component score coefficients and the original normalized values of each indicator can be calculated for i = 1, 2, . . . , 8. The specific formula for livelihood vulnerability constructed here from our data is:

$$LVI = 0.0891 F_1 + 0.0790 F_2 + 0.0751 F_3 + 0.0695 F_4 + 0.0686 F_5 + 0.0538 F_6 + 0.0530 F_7 + 0.0525 F_8 \quad (8)$$

2.2.3 Control variables

Since human capital, natural capital, social capital, and financial capital are important factors of production that sustain the livelihood activities of rural households, they were included in the regression model. Human capital is measured by the proportion of the non-working population to total household size, labeled "non-labor ratio" (Liu et al., 2021; Xu et al., 2019), which reflects the ability of the rural household to support the non-working population. The variable "loan" is used to measure financial capital (Javed and Bill, 2022), and indicates the likelihood of obtaining loans, which determines the buffering capacity of the rural household to cope with external shocks and disturbances. Social capital is the social network (Wei et al., 2021), reciprocal norms and trust that rural households form in the process of interacting with other social agents, and is represented by "phone charge". Natural capital refers to the natural resources owned by the rural household (Quandt and Neufeldt, 2019) that are used to produce products or provide other resource flows and services to the rural household, and is measured by "land area". Table 2 shows the corresponding variable settings and descriptive statistics.

2.3 Model construction

Empirical experience and related studies suggest that the relationship between livelihood resilience and livelihood vulnerability of rural households may be nonlinear (Usamah et al., 2014), and therefore the analysis was conducted using a threshold regression model. The phenomenon when one economic parameter reaches a specific value and causes a sudden shift in another economic parameter to another form of development (structural mutation) is called the "threshold effect", and the threshold value as the cause of the phenomenon is also called the "threshold value". The model is constructed as follows:

$$LVI_i = \beta_0 + \beta_1 \text{Non} - \text{labor ratio}_i + \beta_2 \text{Loan}_i + \beta_3 \text{Phone charge}_i + \beta_4 \text{Land area}_i + \{\rho_1 Fr_i\} I[Fr_i \le \gamma] + \{\rho_2 Fr_i\} I[Fr_i > \gamma] + e_i \quad (9)$$

where LVI_i is the dependent variable, namely, livelihood vulnerability, "Non-labor ratio$_i$", "Loan$_i$", "Phone charge$_i$, and "Land area$_i$" are control variables, i = 1, 2, 3, ... denotes the *i*th rural household, Fr_i is livelihood resilience, β_i is the output coefficient of each factor of production, ρ_1 and ρ_2 are the coefficients of the independent variables before and after the thresholds, $I[.]$ is an indicator function, γ is the threshold value, e_i is a random interference term. Threshold variables can be both exogenous and explanatory variables in the model, and in this study the threshold variable was livelihood resilience. If we consider

further the effect of generalized resilience and specific resilience on the livelihood vulnerability of farmers, the model used is:

$$LVI_i = \beta_0 + \beta_1 \text{Non} - \text{labor ratio}_i + \beta_2 \text{Loan}_i + \beta_3 \text{Phone charge}_i + \beta_4 \text{Land area}_i + \{\rho_1 Fa_i\} I[Fr_i \le \gamma] + \{\rho_2 Fa_i\} I[Fr_i > \gamma] + e_i \quad (10)$$

$$LVI_i = \beta_0 + \beta_1 \text{Non} - \text{labor ratio}_i + \beta_2 \text{Loan}_i + \beta_3 \text{Phone charge}_i + \beta_4 \text{Land area}_i + \{\rho_1 Fv_i\} I[Fr_i \le \gamma] + \{\rho_2 Fv_i\} I[Fr_i > \gamma] + e_i, \quad (11)$$

where Fa_i and Fv_i are the independent variables for general and specific resilience.

3 Results

3.1 Descriptive statistics of livelihood resilience

3.1.1 Differences in livelihood resilience across rural households

Using relocation status as a classification criterion, Table 2 shows the differences in livelihood vulnerability of different farmers. We see that the livelihood vulnerability of relocated households (−0.042) was significantly lower than local (0.091), while the livelihood resilience of relocated households was slightly higher than that of local households. This suggests that as a positive intervention to deal with the cycle of poverty, migration policies to reduce disasters have led to increased levels of livelihood resilience and have significantly reduced the vulnerability of relocated households. Thus, for relocated households whose production and living environment have been greatly transformed, the ability to withstand risks is enhanced after they go through the complicated economic recovery and reconstruction processes in the relocated areas.

3.1.2 Number of different livelihood activities and livelihood resilience

Rural households' livelihood strategies are dynamic in nature and change with the interaction between their own livelihood capital and external environmental conditions, showing gradual development from mainly agricultural to diversified livelihood strategies including labor and non-farm business. Table 3 exhibits the association between livelihood resilience and the number of livelihood activities and shows that as the number of rural households' livelihood activities increased, general resilience showed an increasing trend, and both specific resilience and livelihood resilience showed a decreasing trend.

TABLE 3 Relationship between Livelihood Resilience and the number of Livelihood Activities.

Number	Fr	Fa	Fv	N
1	0.955	0.161	0.883	225
2	0.604	0.186	0.525	202
3	0.473	0.200	0.364	167
4	0.395	0.203	0.263	25
Overall	0.641	0.181	0.601	619

3.1.3 Fitted graph of livelihood resilience and livelihood vulnerability

To show the relationship between livelihood resilience and livelihood vulnerability of rural households, we use first-order fitting graph analysis, second-order fitting graph analysis and kernel density regression fitting graph analysis. The results of these graphical analyses are shown in Figure 3.

Livelihood resilience shows an overall downward effect on the livelihood vulnerability of all samples. The kernel density regression fitting results show that the marginal effect of livelihood resilience on livelihood vulnerability fluctuates to some extent after a critical value is reached, and the magnitudes of the critical value and marginal effect need to be further estimated by regression models.

3.2 Threshold effect test for livelihood resilience

We test whether the livelihood resilience of relocated households, local households and all rural households have threshold effects on livelihood vulnerability. The results of the test for all rural households are shown in Figure 4.

When both the threshold variable and the explanatory variable are livelihood resilience, the LM estimate is 15.74 and the p-value is 0.0098, rejecting the original hypothesis that there is no threshold effect. That is, there is a threshold effect of all rural households' livelihood resilience on livelihood vulnerability, and the preliminary estimate of the threshold value is 0.3818 with estimated 95% confidence interval is [0.3225, 1.0583]. Due to space limitation, the threshold test details of relocated and non-relocated households is not listed.

The threshold effect test and confidence interval of different sample rural households are obtained by taking the livelihood resilience of rural households as the threshold variable and livelihood resilience, general resilience and specific resilience as independent variables. The results are shown in Table 4. The livelihood resilience of relocated households, local households and all households have a threshold effect on livelihood vulnerability. For the same explanatory variables, the thresholds for livelihood resilience were higher for relocated households than for local households, and the thresholds for general resilience and specific resilience were lower than for local households.

3.3 Impact of livelihood resilience on livelihood vulnerability

3.3.1 Results

Table 5 describes the results of livelihood resilience on rural households' livelihood vulnerability for different samples. Livelihood resilience, general resilience and specific resilience are

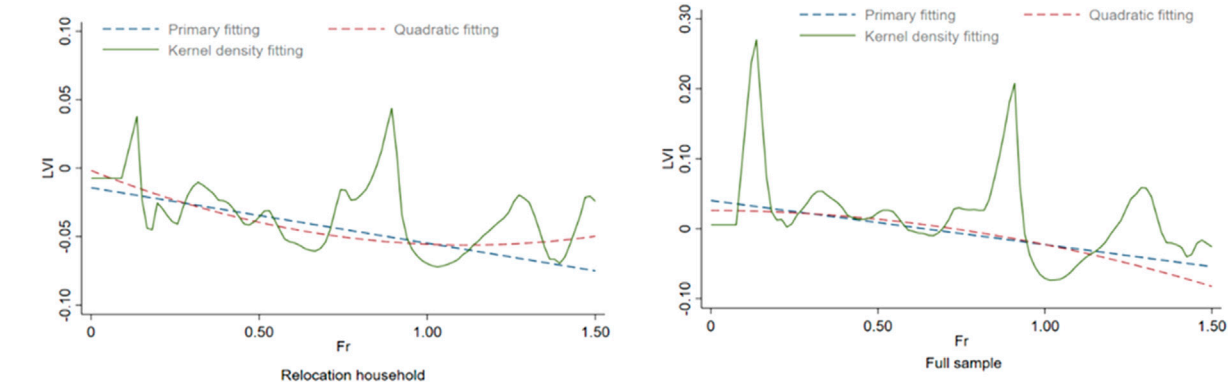

FIGURE 3
Graphical fitting of livelihood resilience and vulnerability.

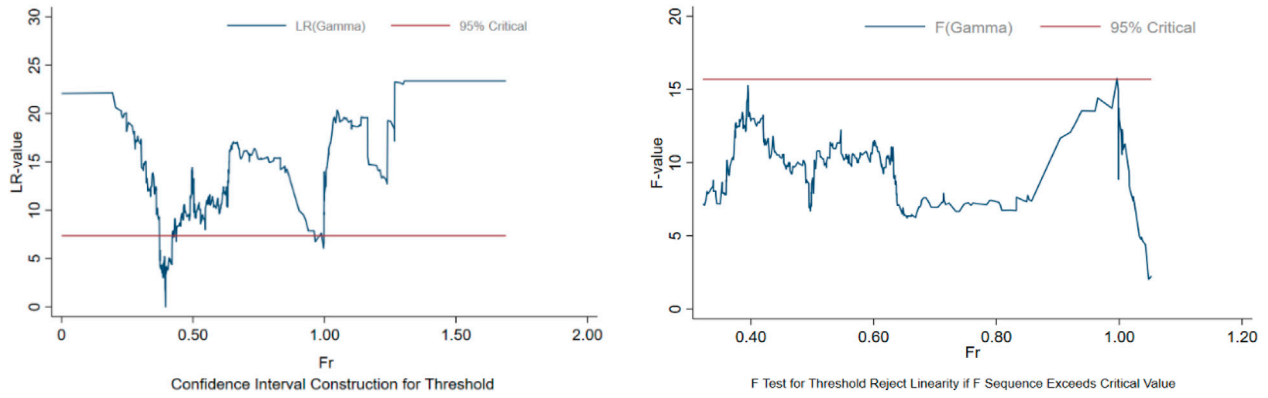

FIGURE 4
Threshold effect test and confidence interval estimation of resilience of households.

TABLE 4 Threshold effects and confidence interval.

Group	Dependent variable	LM-value	*p*-value	BS	Threshold estimates	95% confidence interval
Relocated	Fr	9.56	0.0636	5,000	0.6548	[0.3297,1.1031]
	Fa	34.46	0.0000	5,000	0.4458	[0.3747,0.5600]
	Fv	12.45	0.0002	5,000	0.3783	[0.3297,0.5876]
Non-relocated	Fr	16.02	0.0448	5,000	0.5039	[0.3222,0.8573]
	Fa	18.30	0.0130	5,000	0.5292	[0.3222,0.8573]
	Fv	19.80	0.0014	5,000	0.5055	[0.4827,0.6293]
All	Fr	15.74	0.0098	5,000	0.3818	[0.3225,1.0583]
	Fa	36.76	0.0004	5,000	0.5292	[0.3747,0.6377]
	Fv	29.86	0.0002	5,000	0.3818	[0.3225,0.6031]

Threshold effect exists if *p*-value is less than 0.1.

included in the regression model as explanatory variables. Model 1-Model 3, Model 4-Model 6 and Model 7-Model 9 refer to the regression results of relocated households, local households and all rural households, respectively.

Model 1. shows a negative effect on livelihood vulnerability until the livelihood resilience of relocated households reaches the threshold and remains significant at the 5% level of significance after crossing the threshold of 0.6548. Model 2 shows that when

TABLE 5 Impact of livelihood resilience on livelihood vulnerability.

Variable	Relocated			Non-relocated			All		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Fr (fr≤γ)	−0.107**			0.236*			0.155*		
Fr (fr>γ)	−0.047**			0.042			−0.031		
Fa (fr≤γ)		0.641***			0.850***			0.621***	
Fa (fr>γ)		0.180***			0.295***			0.207***	
Fv(fr≤γ)			0.133***			−0.225**			0.031
Fv(fr>γ)			−0.027			0.246***			−0.102***
Non-labor ratio	−0.015	0.010	−0.026	0.040	0.067	0.061	0.010	0.024	0.009
Loan	−0.024***	−0.020***	−0.022***	−0.045***	−0.034***	−0.039***	−0.034***	−0.030***	−0.032***
Phone charge	0.008	0.007	0.007	0.004	−0.014	0.013	0.004	0.002	0.003
Land area	0.0005*	0.0005**	0.0004*	−0.0006*	−0.0005**	0.0006**	0.0006***	0.0006***	0.0006***
Constant	0.079**	−0.032	0.039	0.153	0.094*	0.302***	0.111***	0.026	0.144***
N	424	424	424	195	195	195	619	619	619

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

livelihood resilience crosses the threshold value of 0.4458, the marginal effect of universal resilience on livelihood vulnerability changes from 0.641 to 0.180. Model 3 shows that specific resilience has a significant positive contribution on livelihood vulnerability before livelihood resilience reaches a threshold of 0.3783. When livelihood resilience crosses the threshold of 0.3783, specific resilience has a negative but not notable impact of relocated households.

Model 4. shows a positive effect on livelihood vulnerability until local household livelihood resilience reaches a threshold value of 0.5039, and a non-significant effect on livelihood vulnerability after crossing this threshold. Model 5 shows that the marginal effect of universal resilience on livelihood vulnerability changes from 0.850 to 0.295 when livelihood resilience crosses the threshold of 0.5292. Model 6 shows that specific resilience has a negative contribution before crossing the threshold of 0.5055, but after crossing the threshold, it has a significant positive impact. Model 7 shows a positive effect on livelihood vulnerability until livelihood resilience of all rural households reaches the threshold, and a negative effect after crossing the threshold of 0.3818, but the effect is no-significant. Model 8 shows that universal resilience has a positive effect on livelihood vulnerability. Model 9 shows that after livelihood resilience reaches the threshold of 0.3818, specific resilience has a significant negative impact, although previously it had an insignificant effect.

3.3.2 Robustness tests

The results of robustness tests for the relocated households are shown in Table 6.

Robustness tests usually examine whether the evaluation methods and variables are relatively stable and consistent in their interpretation when certain parameters of the model are changed. The above threshold regression for rural households' livelihood resilience and livelihood vulnerability may have endogenous problems due to the cross-sectional data used. It is therefore necessary to check whether the regression results are robust by controlling some variables. Large-scale relocation in Shaanxi Province began in 2011. Besides disaster reduction relocation, there is also a small amount of synchronous relocation, and the resettlement methods fall mainly into two types: centralized relocation and decentralized relocation, which may affect the estimated results. The regression models that introduce the type of relocation and resettlement method as control variables for relocated households are model 10-model 12 and model 13-model 15, respectively. Overall, the test results for the main indicators when controlling for different variables are similar to the regression results of models 1-3, the threshold values of livelihood resilience are the same, the marginal effect of each indicator fluctuates slightly but the action trend is consistent, which indicates that the regression results are robust.

4 Discussion

Disaster resettlement provides an opportunity to explore environmental and climate-related issues in a rapidly changing global context (Xu et al., 2022). It has many objectives including reducing livelihood vulnerability and improving and enhancing livelihood resilience and adaptation. We have explored household livelihood resilience in the case of disaster resettlement. The results show that livelihood resilience, general resilience and specific resilience of relocated households are slightly higher than those of local (non-relocated) households. This indicates that the relevant coping not only improves rural households' living environment and increases their income, but also enhances their adaptive capacity (Justin and Brooke, 2020; Patrick et al., 2022). With an increase in the number of livelihood activities, the livelihood resilience and

TABLE 6 Results of robustness tests of relocated households.

Variable	Introducing control variables					
	(10)	(11)	(12)	(13)	(14)	(15)
Fr (fr≤γ)	−0.116**			−0.108**		
Fr (fr>γ)	−0.045**			−0.046**		
Fa (fr≤γ)		0.619***			0.642***	
Fa (fr>γ)		0.177***			0.180***	
Fv(fr≤γ)			0.137***			0.134***
Fv(fr>γ)			−0.020			−0.028
Non-labor ratio	−0.007	0.016	−0.019	−0.015	0.010	−0.026
Loan	−0.022***	−0.019***	−0.021***	−0.024***	−0.020***	−0.023***
Phone charge	0.008	0.007	0.007	0.008	0.007	0.007
Land area	0.0004*	0.0005**	0.0004*	0.0004*	0.0005**	0.004*
Constant	0.121***	0.001	0.073**	0.080**	−0.032	0.038
Control variable	Resettlement type			Resettlement reason		
N	424	424	424	424	424	424

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

specific resilience show a decreasing trend and general resilience shows an increasing trend. A quantitative estimation of the vulnerability in the livelihood system of rural households suggests that although the livelihood vulnerability of relocated households is significantly lower than that of local households, there remains a certain degree of vulnerability risk.

In terms of the relationship of livelihood resilience on livelihood vulnerability, there is a significant threshold effect: for relocation households, livelihood resilience has a significant negative impact on livelihood vulnerability, which decreases as livelihood resilience increases. Some studies have shown that participation in relocation increases the wellbeing of rural households and significantly reduces their vulnerability. In addition, the marginal effect of general resilience is to decrease livelihood vulnerability. This is consistent with previous studies (Li et al., 2021b; Zhang et al., 2022b). In general, low income from agriculture forces farmers to increase indebtedness and therefore destroys the farmers' livelihood resilience (Reddy et al., 2020). However, as relocated rural households are subject to various policy subsidies as well as welfare preferences (Morris et al., 2009; Li and Zander, 2020), their overall income level increases significantly. This has solved the double dilemma of eco-environmental protection and social and economic development to a certain extent. Although the disaster resettlement policy has increased the overall income level of rural households in the research area by 1,815.52 yuan, which significantly reduced their vulnerability at the income level (Liu et al., 2023), the welfare effect brought by the policy will gradually decrease with the continuous development of relocation (Sina et al., 2019). It is not advisable to rely solely on government subsidies to reduce the vulnerability of farmers. For the same explanatory variables, the threshold value of livelihood resilience of relocated households is slightly higher than local households, and the threshold value of general resilience and specific resilience is slightly lower than that for local households. According to Folke (Folke, 2006), the threshold value of livelihood resilience reflects the maximum disturbance that a livelihood system in a stable state can withstand while maintaining basic structure and function. The slightly higher threshold value further indicates that with the gradual implementation of the relocation project, the efficiency of targeting and the effectiveness of identification of the project as well as the effectiveness of the policy have been improved. Relocation improves the ability of rural households to cope with external changes and risks.

Disaster resettlement is a long-term process for rural households to restore and rebuild livelihoods; therefore, it will take some time for the relocation to enter the final stage of development and integration (Guo and naim, 2018). The specific livelihood resilience in Model 3 and Model 6 is linked to the livelihood diversity of rural households, and livelihood diversification before reaching a critical value instead increases the possibility that rural households will fall into a vulnerability trap, which indicates that diversified livelihoods have certain limitations (Peng et al., 2022). Combined with the results in Table 3, in the early stage of relocation, single livelihood activities of rural households are transformed into diversified livelihoods, which leads to a chance of livelihood transformation (Chidozie and Chang-Richards, 2022). The diversified orientation of livelihood activities ignores the reproduction dilemma of rural households and takes capital for industrial development from the scarce resources, which entails livelihood risks. In addition, our interviews show that many rural households try to generate income by growing tea and raising livestock. However, such production activities not only occupy limited human resources and family funds, but also have certain requirements on planting and breeding technology, so the income is not satisfactory. After introducing the relocation type and relocation reason as control variables into the regression model of relocated households, we find that when

different variables are controlled, indicators, threshold values, and significances are consistent with those before, indicating that the regression result is robust.

This article has clear limitations. First, using cross-sectional data only offers a "snapshot" of livelihood features. Moreover, this survey only covered Ankang City in southern Shaanxi, while the Shaanxi Disaster Prevention and Resettlement Project also covered parts of northern Shaanxi and Guanzhong. Thus, the general significance of the research results is limited. Persistent changes in the livelihood resilience and vulnerability of relocated were difficult to observe. At the same time, although several developed frameworks and indicators have been adopted to assess vulnerability, indicators may still not all-inclusive. Also, the differences between households surveyed in different regions may affect their participation and create bias in assessing the variables of interest. The threshold regression analysis method used in this paper is limited by the survey data and relevant indicators. Therefore, there is potential for further improvement of the methodology used in this study. Third, although the survey was conducted in rural areas of China, the results of the survey are not representative of the situation in all rural areas. This is because rural areas vary greatly, with different levels of development and characteristics in different regions. Therefore, these differences and specific contexts need to be taken into account when applying the results of the survey to less developed areas.

5 Conclusion

This paper analyzes the impact of livelihood resilience on livelihood vulnerability of rural households in Ankang, Southern Shaanxi, China. There was a significant threshold effect of livelihood resilience on the livelihood vulnerability of rural households. Compared with local households, the livelihood vulnerability of relocated (−0.042) was significantly lower than local households (0.091), an increase in livelihood resilience significantly reduced the livelihood vulnerability of rural households, and the effect of general resilience on livelihood vulnerability showed a decreasing marginal effect. Before the specific resilience exceeds the threshold, it has a positive effect on livelihood vulnerability, but this effect disappears when the resilience exceeds the threshold. This indicates that relocation can significantly reduce the livelihood vulnerability of households in disaster-prone areas.

Resilience and vulnerability are both currently hot topics in the global development, and this study offers specific information concerning the linkages between resilience and vulnerability in resettlement settings. Based on the findings of the study, we suggest that attention should be paid to the role of resilience in the livelihood status of rural households, while the link between livelihood resilience and vulnerability should be utilized to formulate follow-up support policies. Consequently, the rural households in China could have improved livelihood resilience through a number of measures to reduce their vulnerability including strengthening the skills training policies, helping rural households engage in non-farm employment, promoting industrial integration in rural resettlement areas and enhancing their practical learning capacity to promote sustainable livelihoods.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Ethics statement

Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

WL: Data curation, Writing–original draft, Writing–review and editing. JaL: Formal Analysis, Writing–original draft, Writing–review and editing. JX: Data curation, Writing–review and editing. JeL: Data curation, Writing–review and editing. MF: Supervision, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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