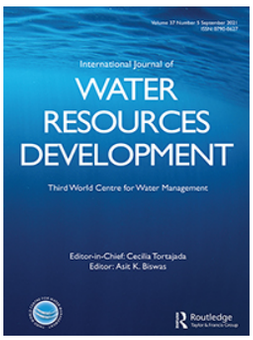

International Journal of Water Resources Development

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cijw20

Rethinking livelihood resilience after development-induced displacement and resettlement: a case study of Qianping Reservoir

Yichun Gong, Kaiwen Yao, Ruilian Zhang, Bingwen Liu & Feilong Wang

To cite this article: Yichun Gong, Kaiwen Yao, Ruilian Zhang, Bingwen Liu & Feilong Wang (2021) Rethinking livelihood resilience after development-induced displacement and resettlement: a case study of Qianping Reservoir, International Journal of Water Resources Development, 37:5, 841-864, DOI: 10.1080/07900627.2020.1790340

To link to this article: https://doi.org/10.1080/07900627.2020.1790340

INTERNATIONAL JOURNAL OF WATER RESOURCES DEVELOPMENT
2021, VOL. 37, NO. 5, 841–864
https://doi.org/10.1080/07900627.2020.1790340

Rethinking livelihood resilience after development-induced displacement and resettlement: a case study of Qianping Reservoir

Yichun Gong[a], Kaiwen Yao[a], Ruilian Zhang[b], Bingwen Liu[a] and Feilong Wang[a]

[a]School of Water Resources and Hydropower Engineering, North China Electric Power University, Beijing, China; [b]Centre for Social Responsibility in Mining, Sustainable Minerals Institute, The University of Queensland, Brisbane, Australia

ABSTRACT

To explore the livelihood problems following development-induced displacement and resettlement, this article selects 234 affected families of the Qianping Reservoir in China and builds a livelihood resilience inferred measurement model to assess and verify their livelihood resilience. The research shows that households that have a reasonable income structure or that resettled near their original residence have higher livelihood resilience. Moreover, the proportion of agricultural income and physical capital have the most significant impact on livelihood resilience compared with other socio-economic indicators. These findings can help individuals make better preparations in advance and guide governments to do well in assistance after resettlement.

ARTICLE HISTORY
Received 16 December 2019
Accepted 24 June 2020

KEYWORDS
Livelihood resilience; reservoir-affected families; livelihood resilience vulnerability; adaptability; China

Introduction

In September 2015, the United Nations promulgated 'Transforming Our World: The 2030 Agenda for Sustainable Development' and noted that eliminating poverty in all its forms and manifestations is the greatest challenge faced worldwide and an indispensable element of sustainable development (United Nations, 2015). China considers the sustainable development agenda along with the country's long-term development plan and pays attention to people's livelihoods in an effort to solve the problem of poverty, especially the livelihoods of reservoir-affected persons who are forced to relocate and resettle because of water conservancy projects (Wilmsen et al., 2019). Studies have found that when people leave their original homes and jobs, they face many challenges, including settling their families into a new life and finding new jobs (Internal Displacement Monitoring Centre, 2013; International Federation of Red Cross, 2012) or new ways to make a living (Camilo, 2007). The impact of displacement differs from the impacts of unpredictable disasters such as earthquakes, tsunamis or hurricanes, and of protracted and recurrent crises such as droughts and floods. People have individual tolerance for such risks and can draw lessons from multiple disasters to minimize losses

CONTACT Kaiwen Yao kwyao@ncepu.edu.cn
Supplemental data for this article can be accessed here.

(Sina et al., 2019). Although reservoir-affected persons recognize the risk before they are forced to relocate, they have no experience that would prepare them to deal with the associated challenges. Relocation and resettlement disrupt their normal livelihood activities, and whether they can attain sustainable development is still generally unknown.

The concept of resilience originated in the field of materials and was first introduced into ecosystem research by Holling's pioneering article in 1973. Later, resilience research was gradually extended to other complex system sciences, such as the social sciences, geography and sustainability. Walker and Salt (2006) defined resilience as the 'capacity of a system to absorb disturbance and still retain its basic function and structure'. Adger (2006) suggested that resilience includes not only the ability to self-organize but also the ability to learn and adapt. However, there is a growing consensus that the concept of resilience must change for different research objects and perspectives. One perspective on resilience that has been adopted by emergency response agencies and nongovernmental organizations focuses on improving living standards and resisting adverse events (Marchese et al., 2018). Resilience has become an important criterion in measuring individual or regional development capacity. With the wide application of the resilience concept in social science research, researchers have integrated it into more microsocial problems, for example, applying it to livelihood issues. Livelihood resilience is considered the key in exploring sustainable livelihoods (Cai et al., 2018; Peng et al., 2019; Sina et al., 2019). Therefore, high priority is given to building reservoir-affected persons' livelihood resilience.

Household units play a central role in managing responses to external stimulation (Jones & Tanner, 2017). Household-scale analysis shows that assumed capabilities and vulnerabilities may differ significantly from those imagined or measured at the macro-scale (Toole et al., 2016). Even if resettlement families enjoy the same compensation policy, they recover at different speeds because of their different family resources or resettlement ways (Yan et al., 2011). This article focuses on the analysis of livelihood resilience at the household level. Specifically, this article uses the resilience inference measurement framework to build a model to assess the livelihood resilience of reservoir-affected families (RAFs), and uses *K*-means clustering to divide the resilience of these families into four categories from weak to strong, and then uses discriminant analysis to verify the accuracy of the prior resilience ranking and determine the impact of socio-economic indicators on livelihood resilience. We mainly consider two questions: Do RAFs have different levels of livelihood resilience? And what social and economic characteristics can improve their resilience? Understanding the characteristics of the RAFs' livelihood resilience and the particular challenges they face can provide insight into the elements that need to be considered when planning for recovery and adaption (Ainuddin & Routray, 2012).

Literature review

The concept of 'resilient livelihood' was first introduced by Chambers and Conway (1992) as part of the concept of 'sustainable livelihood'. Brand and Jax (2007) and Nyamwanza (2012) elaborated that livelihood resilience can be understood as the process through which households respond to, recover from and learn from changes and disturbances and transform their livelihood patterns to adapt to changes and challenges. According to an FAO report, livelihood resilience is the ability to cope with external shocks and return to

a stable state (Food and Agriculture Organization of the United Nations, 2013a, 2013b; Thulstrup, 2015). In summary, resilience is regarded as a broad concept that includes vulnerability in the face of interference and adaptability after interference (National Research Council, 2012).

The abstract and multidimensional nature of resilience make it challenging to measure, and the methods for doing so are heavily contested (Cumming et al., 2005). The methods most commonly used in current studies are conceptual framework, index-oriented analysis, and questionnaires and interviews (Fang et al., 2018). Marschke and Berkes (2006) proposed livelihood strategies to build resilience and used surveys of local residents' satisfaction to measure resilience. Sallu et al. (2010) used principal component analysis to determine family resilience over time through livelihood strategies. Speranza et al. (2014) constructed a comprehensive analysis framework of livelihood resilience with three dimensions: buffer capacity, self-organization and learning capacity. Thulstrup (2015) designed questionnaires including five kinds of capital – natural, physical, financial, human and social – and used semi-structured interviews and participatory evaluation to assess resilience. Quandt (2018) proposed the 'household livelihood resilience approach', which takes the sustainable livelihood framework as its basis and uses five kinds of sustainable livelihood capital to measure livelihood resilience. Fang et al. (2018) used structural dynamics to measure and analyze livelihood resilience and its influencing factors considering four aspects: livelihood quality, livelihood promotion, livelihood provision and disaster stress. Sina et al. (2019) developed a conceptual framework with the background of involuntary displacement after natural disasters. Her indicators of livelihood resilience were based on field surveys of four villages.

Although many scholars have carried out quantitative assessments of livelihood resilience, there are still three challenges in measuring it (Ingrisch & Bahn, 2018). First, it is difficult to identify the structural effects and determinants of resilience because it is defined differently in the context of different research objectives (Heng et al., 2018). Second, the influencing factors and weights are set subjectively, which limits the accuracy and applicability of the results (Bruneau et al., 2003; National Research Council, 2012). Third, empirical data are rarely used to validate resilience studies (Bruneau et al., 2003; Chang & Shinozuka, 2004; Li et al., 2016). To assess resilience accurately and objectively, Lam, Reams, et al. (2015) developed the RIM model to assess resilience quantitatively and study the key variables affecting it. The RIM method has been applied to coastal countries in the Caribbean region and to counties in Sichuan Province after the Wenchuan earthquake. Because the model defines an overall framework for measuring resilience, its application is not limited to specific disaster types or indicators. The RIM model is based on a theoretical rationale but also considers empirical data for verification, so it overcomes two of the difficulties in measuring resilience: verifying the resilience scores and making statistical inferences (Li et al., 2016).

Methods

Study area and data

This article studies households that were relocated for the construction of the Qianping Reservoir. The reservoir is in Ruyang County, Luoyang City, Henan Province, China (Figure 1).

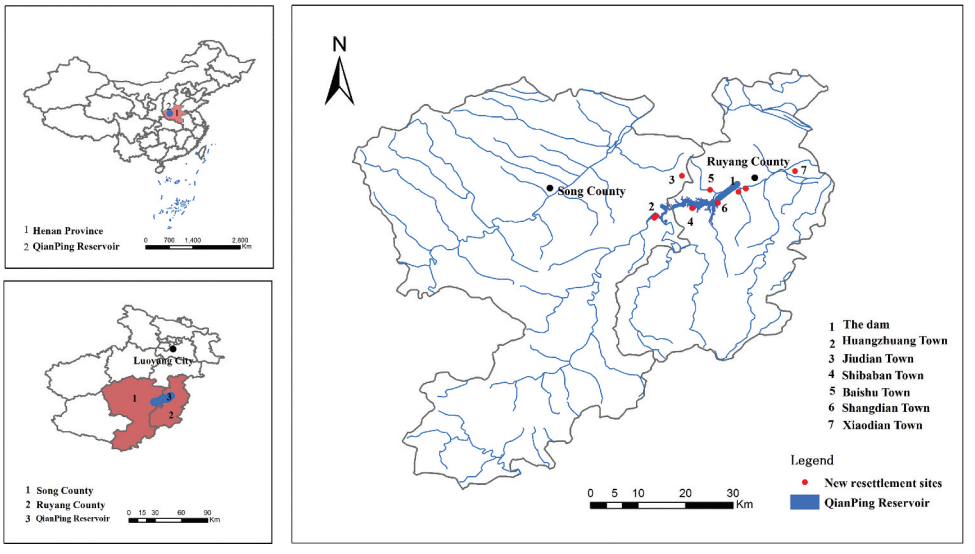

Figure 1. Location of the study area.

It is a large-scale project with flood control as its primary function, along with water supply, irrigation, and power generation. It has affected 20 villages in five townships in the region, with 13,489 people targeted for resettlement. The project had a significant impact on the production and lives of people in this area. We chose Qianping Reservoir as a research case for two reasons. First, Qianping Reservoir is in Ruyang County, where the economy is not well developed and the relationship between people and land is tense. Most RAFs have single income channels and low production efficiency, and their livelihood problems are more prominent. Second, Qianping Reservoir provides more options for resettlement than other Chinese reservoirs. The resettlement sites are of four types – local village, neighbouring village, neighbouring town and county town – which helps us in making a comparative analysis of the livelihood resilience of the groups who choose different resettlement sites.

The use of field surveys to gather microdata on farmers can effectively avoid errors caused by using second-hand data for analysis, overcome data limitations, and reduce dependence on the econometric statistical model (Liu et al., 2018). Our data come from the team's field investigation. Using the sampling survey method, 234 affected families were selected and followed in 2016, 2017 and 2018. Through questionnaires and semi-structured interviews, information was gathered on the livelihoods of the RAFs before, during and after relocation. The survey covered basic family information before and after resettlement (family size, dependency ratio, education, psychological acceptance, resettlement methods), exposure (economic losses, housing structures, loan situations), livelihood capital (cultivated land area, income, property status, social network, employment rate) and adaptability (satisfaction with housing and living environment, social welfare, livelihood type). According to the questionnaire responses, the 234 households included 1269 people, of whom 50.6% were men. Before relocation, the average family size was 5.42, average dependency ratio was 0.93, average length of education was 6.18 years, per capita disposable income was RMB 9366, and per capita cultivated land area was 0.54 hectares (data calculated by the authors).

To analyze the characteristics of the livelihood resilience of different groups of RAFs, we classify households as follows. In terms of income composition (livelihood strategy), the Chinese Ministry of Agriculture divides households into pure peasants (for whom agricultural production provides more than 80% of household income); a first type of part-time farmers (50–80% of household income); a second type of part-time farmers (20–50% of household income); and pure nonfarming households (less than 20% of household income). The location of resettlement is classified as near the village; outside the village but not outside the rural area; outside the rural area but not outside the county; or in a county. Households are also classed as low-income (with less than the local average income) or high-income (with the local average income, or more).

The livelihood resilience inference measurement model

In this article, the definition of resilience includes vulnerability to interference and adaptability to new environments (National Research Council, 2012). The RIM model proposed by Lam, Reams, et al. (2015) uses exposure, damage and recovery to construct a framework for assessing resilience through the results of vulnerability and adaptability (Figure 2). Vulnerability is the inability to minimize damage or shock at the time of disaster (Folke et al., 2002). Adaptability is the ability to bounce back to a new steady state after a disaster (Brooks et al., 2005). And vulnerability and adaptability can reflect the condition of livelihoods before, during and after disasters.

Here, our topic is the livelihood resilience of RAFs, and it can be evaluated based on the RIM model. Involuntary relocation for reservoir construction is a policy intervention in the form of an external shock, which shakes the original livelihood of RAFs (livelihood strategies are forcibly suspended or changed), so their livelihood capital is lost. After resettlement, the RAFs' livelihood capital gradually re-accumulates, and their livelihood activities gradually recover. Therefore, we build the livelihood resilience inference measurement (LRIM) model of RAFs with three dimensions: shock, loss and recovery (Figure 3).

- *Shock* refers to the extent to which the livelihood behaviour of RAFs has been destroyed. Because RAFs have different livelihood strategies and abilities, their livelihoods are impacted to different degrees and in different ways. The sources of risk are the reduction of production and operation places (such as arable land or shed area), the loss of employment opportunities (such as the decline of working

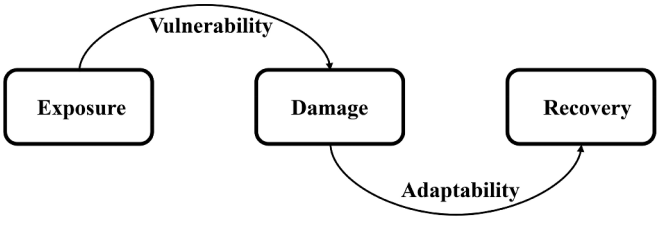

Figure 2. Conceptual framework of the resilience inference measurement model (Lam, Reams, et al., 2015).

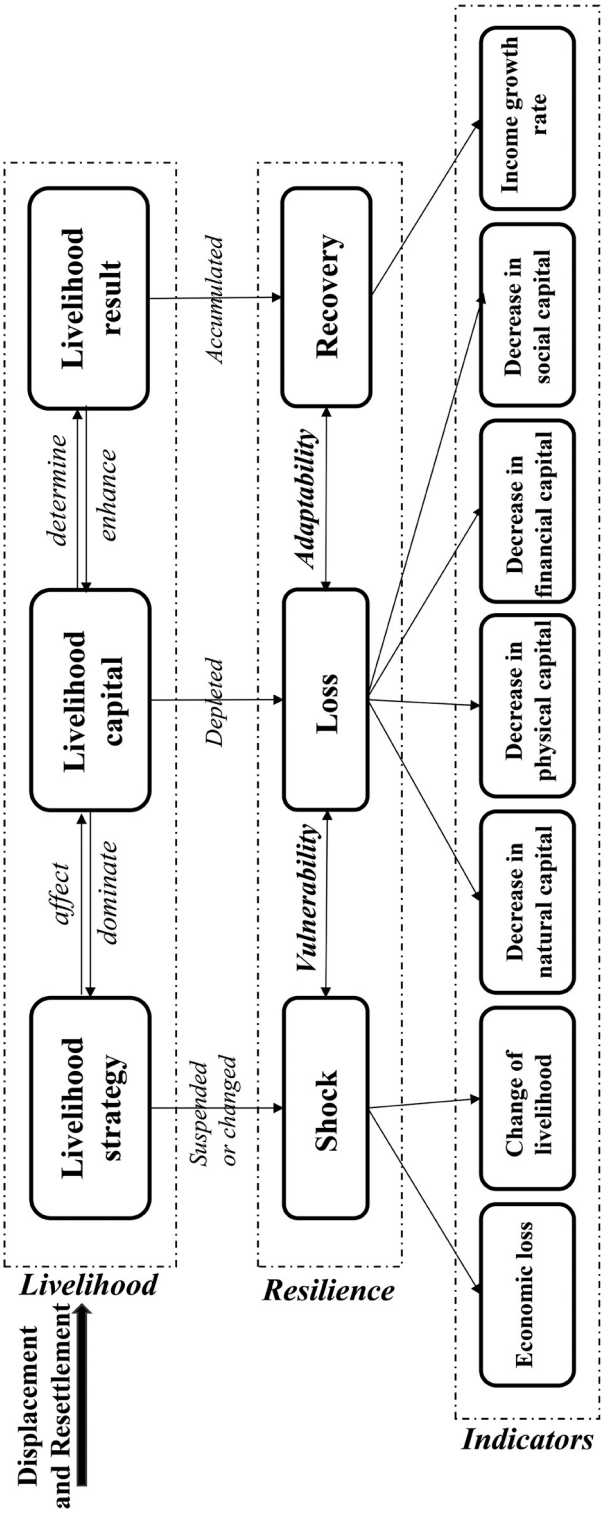

Figure 3. The livelihood resilience inference measurement model of reservoir-affected families.

hours and convenience), and the loss of fixed assets (such as houses and resources invested in production and the lives of the residents). However, the impact of these risks is reflected in direct economic loss and changes in livelihood strategies. Therefore, for quantitative indicators of the shock dimension, we use the ratio of direct financial loss to per capita disposable income and the change in the proportion of agricultural income before and after relocation.

- *Loss* is the response of the families to livelihood shocks. The livelihood capital of RAFs decreases due to a change that halts their economic and social development. Therefore, the reduction of livelihood capital (financial, material, natural, social and human) is taken as a quantitative indicator of loss.
- *Recovery* is the adaptation of RAFs after their relocation, which is mainly reflected in the development of production activities and the improvement of living standards (Karimi & Taifur, 2013). Therefore, income growth is taken as a quantitative indicator of recovery.

Classification of livelihood resilience

According to the characteristics of vulnerability and adaptability, the RIM model divides resilience into four kinds, from low to high: susceptible, recovering, resistant and usurper (Lam, Reams, et al., 2015). Similarly, the livelihood resilience of RAFs can also be categorized from weak to strong: susceptible, recovering, resistant or transformation. Of these, transformation represents an ability to restart, adapt and develop in harsh environment. In general, the susceptible group has high vulnerability and low adaptability, the recovering group has average vulnerability and adaptability, the resistant group has lower vulnerability than the recovering group, and the transformation group has low vulnerability plus high adaptability. For example, the greater the loss caused by the shock, the greater is the vulnerability of RAFs' livelihoods; while the faster is the change from loss to recovery, the stronger is the adaptability of RAFs' livelihoods. The differences in the results of the vulnerability and adaptability of the four classes of livelihood resilience can be illustrated by the slope between the three dimensions of shock, loss and recovery (Figure 4).

Procedures of the LRIM model

The LRIM model also needs two statistical procedures: *k*-means clustering and discriminant analysis. *K*-means clustering is based on the three indicators (shock, loss and recovery) and divides the resilience of the respondents into four categories (susceptible, recovering, resistant and transformation). Discriminant analysis validates the *a priori* resilience ranking using multiple family and socio-economic indicators, which are related to family resources, livelihood capital, and social and economic satisfaction.

K-means clustering is used to rank the livelihood resilience of the 234 sampled families before relocation. In *k*-means clustering, each observation is regarded as a multidimensional vector, and the *n* observations are separated into *k* sets by minimizing the within-cluster sum of squares (Hartigan & Wong, 1979):

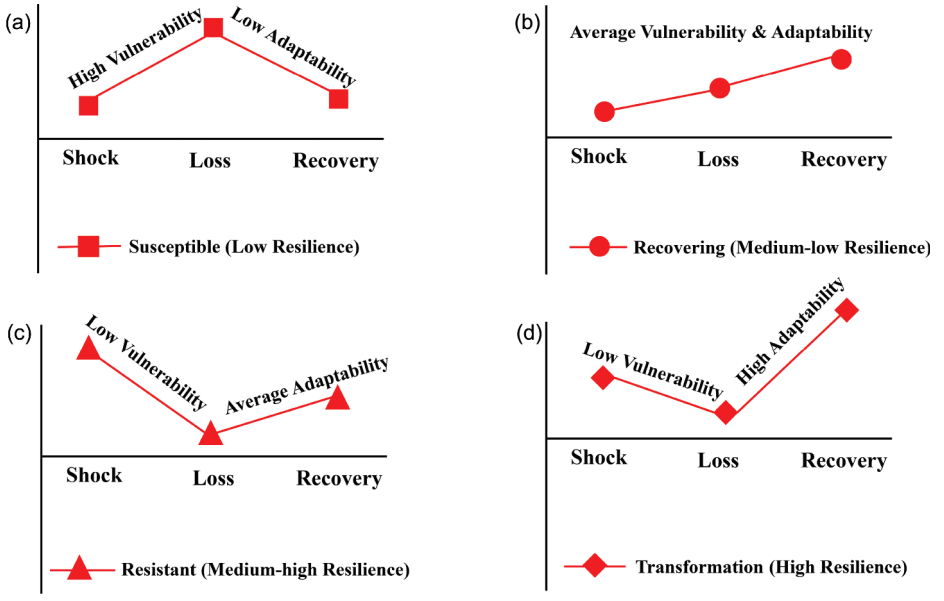

Figure 4. Four states of resilience in the livelihood resilience inference measurement model: (a) susceptible; (b) recovering; (c) resistant; (d) transformation.

$$\arg\, min \sum_{i=1}^{k} \sum_{x_{j \in S_i}} x_j - u_i{}^2 \tag{1}$$

where $S_i (i = 1, 2, \ldots, k)$ are the k sets, $u_i (i = 1, 2, \ldots, k)$ is the mean of all points in S_i, and $x_j (j = 1, 2, \ldots, n)$ is the matrix of observations.

Discriminant analysis combines the predictive variables (independent variables) and the results of k-means clustering (dependent variables) to regroup the observations. Based on previous studies of sustainable livelihood, poverty vulnerability and livelihood resilience (Sok & Yu, 2015), combined with the actual factors of relocation and resettlement in China, such as tension between people and land (He, 2014; Zhao, Tian, et al., 2018), low compensation standards (Du & Li, 2014; Duan & Zhao, 2016) and greater urbanization of resettlement areas (Fan et al., 2015), we designed 20 predictive variables. We suppose that 18 of them increase livelihood resilience: family size, education level, social trust, income, livelihood diversification, psychological acceptance, natural capital, financial capital, physical capital, social capital, satisfaction with production conditions, development opportunities, opportunities for labour transfer, convenience of production and transportation, residential environmental satisfaction, infrastructure satisfaction, satisfaction with social security and satisfaction with community organization. We assume that the other two variables, dependency ratio and proportion of agricultural income, reduce livelihood resilience. We use this relation:

$$D = b_1 x_1 + b_2 x_2 + \ldots + b_n x_n + c \tag{2}$$

where b_i are the discriminant coefficients, x_i are the independent variables, and c is a constant.

The results of the discriminant analysis can be used to calculate an index of the impact of each variable on livelihood resilience (Li et al., 2016; Perreault et al., 1979):

$$\text{potency}_i = \sum_{j=1}^{n} l_{ij}^2 \frac{e_j}{\text{sum of all } e_j} \tag{3}$$

where n is the number of discriminant functions, l_{ij} is the discriminant loading of variable i on function j, and$e_j$is the eigenvalue of function j.

By comparing the classification results of the prior k-means clustering and the later discriminant analysis, we can measure the accuracy of the resilience classification and determine which variables most affect resilience. The model not only includes a verification process but also can predict the livelihood resilience of other RAFs according to the typical discriminant function of discriminant analysis, which shows that the model also has the function of inference (Lam, Reams, et al., 2015).

Result

Data processing

We use survey data to generate statistics for analysis, and we use deviation normalization methods to standardize data, eliminate the effect of the dimension and variance of each index, and improve the comparability of different indicators (Fang et al., 2018). The descriptive statistics and standardized results of the three dimensions (shock, loss and recovery) used in the k-means clustering are shown in Table 1. The 20 predictive variables used in the discriminant analysis are from the survey results on the attitude and status of RAFs before relocation and are shown in Table 2.

Resilience group clustering

The data on the three-dimensional indicators (shock, loss and recovery) were subjected to k-means clustering, and four resilience groups were obtained (Figure 5). The susceptible group showed higher vulnerability and lower adaptability than the other groups throughout the whole process of relocation when subjected to a specific impact. Although the recovering group was less strongly impacted than the other groups, the livelihood capital of these households was depleted, showing vulnerability; still, the households in this group had stronger adaptability than those in the other groups after relocation and resettlement. The resistant group showed lower vulnerability under shock, avoided excessive losses of livelihood capital and presented an ordinary level of adaptability in the recovery process. Although the transformation group faced a higher impact than the other groups, it experienced less loss and apparently achieved recovery in the later period.

Table 3 shows the number of RAFs in each group according to k-means clustering. In terms of livelihood resilience, most of the 234 relocated households belong to the recovering group, followed by the resistant group, the susceptible group and the transformation group. Most of the relocated households in the survey area adapted well to the resettlement sites. But only a few could seize the opportunity to adjust their livelihood

Table 1. Descriptive statistical results for the three dimensions in the livelihood resilience inference measurement model.

Dimension	Indicators	Description and definition of Indicators	Weight	Max.	Min.	Mean	Standard deviation	Mean after standardization
Shock	Economic loss	Ratio of direct economic loss to per capita disposable income (%)	0.5	2253.64	58.56	650.71	4.31	0.27
	Change of livelihood	Change in the proportion of agricultural income before and after relocation (%)	0.5	100	0.74	37.21	0.23	0.37
Loss	Decrease in natural capital	Reduction of land area (hm^2)	0.2	24.47	0	0.51	4.74	0.32
	Decrease in physical capital	Loss of fixed assets for livelihood (%)	0.2	41.33	−3.33	16.25	0.07	0.44
	Decrease in financial capital	Decrease in per annual capita disposable income (yuan)	0.2	17,070	−845.08	2944.85	2359.64	0.21
	Decrease in social capital	Reduction of social networks	0.2	108	−60	28.22	19.52	0.52
Recovery	Livelihood results	Income growth rate after relocation compared with that before relocation (%)	1	50.43	−42.60	9.58	0.18	0.56

Table 2. Descriptive statistics for 20 predictive variables.

Variable	Definition	Mean	Unit
1. Family resources			
1.1 Family size	Household members	5.42	People
1.2 Dependency ratio	Ratio of non-labour population to labour force population	93.25	%
1.3 Average level of education	Average educational years of the family population	6.18	Year
1.4 Social trust	Are there any public officials? (Yes = 1, no = 0)	0.10	-
1.5 Income	Per capita disposable income of the family	9.37	Thousand yuan
1.6 Proportion of agricultural income	Proportion of agricultural income	37.21	%
1.7 Livelihood diversification	The number of types of livelihood activities	2.47	-
1.8 Psychological acceptance	Psychological acceptance of relocation and resettlement (five-item scale, with higher values meaning greater acceptance)	2.86	-
2. Livelihood capital			
2.1 Natural capital	Per capita arable land area	8.05	hm^2
2.2 Financial capital	Ability to borrow from relatives, friends or banks (0–50,000 = 1; 50,000–100,000 = 2; 100,000–150,000 = 3; 150,000–200,000 = 4; more than 200,000 = 5)	2.77	-
2.3 Physical capital	Ratio of productive assets and durable consumer goods to the total items owned by the household	42.19	%
2.4 Social capital	Number of key nodes in social networks	4.97	-
3. Economic characteristics of resettlement sites			
3.1 Satisfaction with production conditions	Satisfaction with the production environment of the resettlement site (five-item scale, with higher values meaning greater satisfaction)	1.89	-
3.2 Development opportunities	Employment opportunities in local enterprises	0.25	-
3.3 Opportunities for labour transfer	Number of migrant workers available	1.94	-
3.4 Convenience of production and transportation	Satisfaction with production and management conditions (five-item scale, with higher values meaning greater satisfaction)	3.15	-
4. Social characteristics of resettlement sites			
4.1 Satisfaction with residential environment	Satisfaction with the housing quality and residential environment in resettlement sites (five-item scale, with higher values meaning greater satisfaction)	3.49	-
4.2 Satisfaction with infrastructure	Satisfaction with the infrastructure of the resettlement site (five-item scale, with higher values meaning greater satisfaction)	3.22	-
4.3 Satisfaction with social security	Satisfaction with social welfare and guarantee policies in resettlement areas (five-item scale, with higher values meaning greater satisfaction)	2.81	-
4.4 Satisfaction with community organizations	Satisfaction with community organization and management in resettlement sites (five-item scale, with higher values meaning greater satisfaction)	2.90	-

strategies and improve their living standards after resettlement. We now consider the similarities and differences in the livelihood resilience of the different types of farmers.

Classification by livelihood strategy

In terms of livelihood resilience, the pure peasant households were mainly in two categories, susceptible and transformation, accounting for 44% and 50% of the

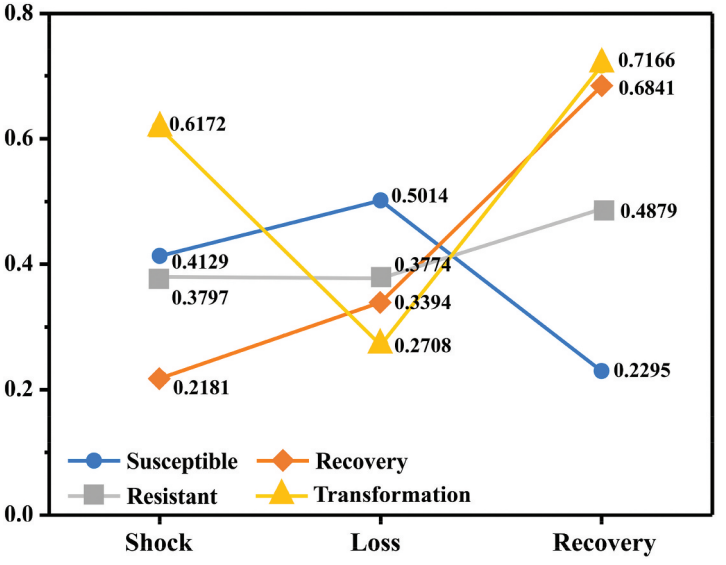

Figure 5. Mean values of the four *k*-means clusters for the three resilience dimensions.

Table 3. Number of cases in each group according to *k*-means clustering.

Cluster		Susceptible	Recovering	Resistant	Transformation	Total
***K*-means**		44	124	48	18	234
Livelihood strategy	Pure peasant households	7	0	1	8	16
	First type of part-time farmers	25	0	14	1	40
	Second type of part-time farmers	12	77	33	7	129
	Pure nonfarming households	0	47	0	2	49
Area of resettlement	Near the village	0	18	8	10	36
	Outside the village but not outside the rural area	33	36	24	3	96
	Outside the rural area but not outside the county	7	44	13	2	66
	In a county	4	26	3	3	36
Income	Low-income households	27	95	42	18	182
	High-income households	17	29	6	0	52

households, respectively. The livelihood of these households was positively affected by relocation and resettlement.

Of the first type of part-time farming households, 63% were in the vulnerable group, and 35% in the resistant group. The adaptability of these households was poor, suggesting that the livelihood activities of these families were firmly tied to the production environment before relocation.

Of the second type of part-time farmers, most (60%) were in the recovering group, while the resistant group accounted for 26%. Although these families had stopped work and production due to relocation, most were able to carry on their livelihood activities in the resettlement sites.

The purely nonfarming households were almost all (96%) recovering, with just 4% transformation. This shows high production efficiency and strong adaptability, but with livelihood activities restricted by the environment before relocation.

Classification by area of resettlement

None of the households that resettled near the village were in the susceptible group, suggesting that the changes in their social and economic environment were small, and they were little affected by the involuntary migration.

For the households that resettled outside the village but not outside the rural area, 34%, 38% and 25% belonged to the susceptible, recovering and resistant groups, respectively, so the long-distance resettlement had a large impact on their livelihoods.

Most of the RAFs that resettled outside the rural area but not outside the county belonged to the recovering group. This suggests that they quickly resumed their production in the resettlement area, where the traffic is more convenient and the level of urbanization is relatively high.

RAFs resettled in a county did not show stronger livelihood resilience. This suggests that although most RAFs could adapt well to their new environment, the pressure of life in the county also posed challenges to their livelihoods.

Classification by income

Most of the low-income families were in the recovering and resistant groups, while most of the high-income families were in the susceptible and recovering groups. Thus, income cannot distinguish the degree of livelihood resilience. In sum, livelihood strategy and area of resettlement have significant effects on livelihood resilience, but income does not.

Discriminant analysis

After *k*-means clustering, discriminant analysis was applied to test whether livelihood resilience could be predicted by family and socio-economic indicators. The results of the discriminant analysis can also be used to check the accuracy of the cluster analysis. Three discriminant functions were obtained using SPSS software. The eigenvalues of the first two discriminant functions are larger, explaining 62.1% and 32.2% of the total variance, respectively, and the results of functions 1 to 3 and functions 2 to 3 in the Wilke lambda test are significant (Tables S1 and S2 in the online supplementary materials). The third function describes only the remaining 5.7% of the variance, so it was omitted from the subsequent research. The typical discriminant function of non-standardized coefficients informs the basic logic of the result classification. Through the discriminant functions, the probability of each relocated household being in a particular resilience category can be calculated, and then the probabilities can be compared to obtain the final classification result. The non-standardized coefficients of the typical discriminant functions 1 and 2 are shown in Table S3 in the online supplementary materials.

The predictive classification results of the discriminant functions and the prior classification results of the *k*-means clustering were 87.2% matched. This means that the 20 predictive variables could be used to correctly distinguish the livelihood resilience of 87.2% of the RAFs; only 29 of the 234 households were misjudged (Table 4). The matching of the susceptible and transformation groups was better than 90%, so the predicted

Table 4. Comparison of the classification results (87.2% of the cases in the original groups were classified correctly).

		Discriminant analysis and prediction of group membership					
		Classification	Resistant	Susceptible	Transformation	Recovering	Total
Initial results of *k*-means clustering	Count	Resistant	41	2	1	4	48
		Susceptible	2	40	0	2	44
		Transformation	1	0	17	0	18
		Recovering	14	2	2	106	124
	%	Resistant	85.4	4.2	2.1	8.3	100
		Susceptible	4.5	90.9	0	4.5	100
		Transformation	5.6	0	94.4	0	100
		Recovering	11.3	1.6	1.6	85.5	100

variables offered better discrimination for these groups. Of the households classified as resistant by *k*-means clustering, 8.3% were classified as recovering by discriminant analysis; and of the households classified as recovering by *k*-means clustering, 11.3% were classified as resistant by discriminant analysis.

Index of impact

We calculate an index of the impact of the 20 considered variables on livelihood resilience (shown in descending order in Table 5). Proportion of agricultural income is the most significant, followed by physical capital, dependency ratio, and satisfaction with the production conditions at the resettlement site. Satisfaction with community organizations, education and income had the least impact on livelihood resilience.

Table 5. Mean and index of impact of variables.

	Mean				
Variable	Resistant	Susceptible	Transformation	Recovering	Index of impact
Proportion of agricultural income	40.65	60.33	59.15	22.43	10.9697
Physical capital	45.57	44.63	28.83	41.88	3.8682
Dependency ratio	1.00	0.60	1.78	0.87	0.7581
Satisfaction with production conditions	2.17	0.27	0.10	0.29	0.5646
Social trust	0.09	0.05	0	0.15	0.2671
Satisfaction with social security	2.50	3.00	3.65	2.75	0.1720
Family size	5.48	5.73	5.3	5.29	0.1437
Satisfaction with infrastructure	3.16	3.00	2.32	3.51	0.1347
Development opportunities	0.19	0.27	0.1	0.29	0.1046
Livelihood diversification	2.66	2.66	1.85	2.40	0.0964
Financial capital	2.59	3.55	2.15	2.68	0.0598
Satisfaction with residential environmental	4.00	3.55	3.3	3.23	0.0534
Opportunities for labour transfer	1.71	1.82	1.25	2.23	0.0526
Social capital	5.49	7.48	5.11	3.69	0.0420
Psychological acceptance	2.73	2.81	2.35	3.04	0.0352
Natural capital	8.13	14.82	4.76	5.93	0.0184
Convenience of production and transportation	3.24	3.05	2.51	3.26	0.0156
Satisfaction with community organizations	2.65	2.61	2.79	3.17	0.0053
Average level of education	6.18	6.47	4.94	6.29	0.0018
Income	8.60	11.01	4.92	9.91	0.0008

Discriminant score

A scatter plot of the livelihood resilience of the 234 relocated households is shown in Figure S1 in the online supplementary materials. Functions 1 and 2 can well classify the four types of households according to livelihood resilience. The transformation group differed significantly from the other three groups in terms of the discriminant score of function 2. The resistant group was distributed between the recovering group and the susceptible group. And the resistant group was close to the recovering group, suggesting similar family characteristics and socio-economic perceptions. This is also why the results of the discriminant analysis and the *k*-means clustering partially intersect. Combining Figure S1 and the mean values in Table 5, the relationship between family and socio-economic indicators and the classification results for livelihood resilience can be explained more intuitively.

The transformation group is indicated by green dots in Figure S1. This group has high values for the dependency ratio and satisfaction with social security and low values for income, education, opportunities for labour transfer, financial capital, physical capital, livelihood diversity, local development opportunities, satisfaction with production conditions, and satisfaction with infrastructure. The high dependency ratio, low labour transfer and scarce employment opportunities indicate low human capital and low livelihood ability. Local governments usually adopt conservative policies to help such families, so these families often benefit from welfare and attention. Social welfare indirectly reduces vulnerability and improves adaptability. Social security and assistance measures also aid the livelihood recovery of such families. Their low income, physical capital and financial capital before relocation also make it less difficult to restore their livelihoods to the original level after relocation.

For the families in the resistant group, mean physical capital, livelihood diversity, and satisfaction with production conditions and the residential environment were higher than other groups. This suggests that these families' livelihood activities are more dependent on places and facilities for production and operation, such as agricultural and side industries, handicraft industries, and secondary and tertiary industries. Their diversified livelihood strategies, high livelihood capacity and livelihood levels provide a buffer for livelihood adjustment during relocation. However, they find it more difficult to quickly restore their livelihood activities to pre-relocation levels.

The recovering group has high values for social trust, infrastructure satisfaction, development opportunities in the new resettlement site, opportunities for labour transfer, psychological acceptance, convenience of production and transportation, and satisfaction with community organizations. This suggests that greater social trust and a more open attitude to relocation indirectly improve the adaptability of RAFs. Therefore, the livelihood resilience of such families mainly depends on the changes in livelihood strategies caused by relocation and the greater development opportunities in resettlement sites.

In contrast, the susceptible group has a higher proportion of agricultural income, larger family size, more financial capital, social capital and natural capital, and higher average income. This shows that high livelihood vulnerability results from single livelihood strategies, low productivity, heavy burdens associated with family composition, and high psychological pressure. Although the dependency ratio of these families is relatively low,

the process of adaptation is difficult due to the low production skills of labourers and the employment pressure after relocation.

Discussion

Whose livelihood is more resilient?

Table 3 shows that livelihood strategy and area of resettlement have a significant impact on livelihood resilience. Next, we compare the characteristics of RAFs in the four groups (susceptible, recovering, resistant and transformation) to explore which types of families are more resilient.

According to the proportions of the four types of RAFs (classified according to livelihood strategy) relative to the total number of households, the standard distribution of each group (from weak to strong: susceptible, recovering, resistant or transformation) among the four types of households was calculated (Table S4 in the online supplementary materials). In the susceptible groups, the number of pure peasant households and the first type of part-time farmers exceeded the standard distribution, indicating relatively weak livelihood resilience. Similarly, there were more of the second type of part-time farmers and pure nonfarming households in the recovering group; more of the first and second types of part-time farmers in the resistant group; and more pure peasant households in the transformation group. That is, the vast majority of the second type of part-time farmers belonged to the groups with higher resilience.

In China, most agricultural production is small-scale and inefficient and depends on the local environment. Due to the strained relationship between people and land, the area of land that farmers own decreases with relocation, and pure peasant households are more vulnerable to forced livelihood changes. The first type of part-time farmers generally use slack time to perform short-term work around their residence and have low production skills and unstable income sources, so they have more difficulty finding another occupation at the new resettlement sites. The second type of part-time farmers rely mostly on nonfarming income, which indicates that they have diversified and high-level livelihoods (Liu et al., 2018). It can be inferred that non-agricultural production skills and experience can cushion the impact of relocation and contribute to the rapid adaptation of these RAFs in their resettlement sites (Han, 2016). Also, most pure peasant households have the strongest livelihood resilience. By combining these results with those of the field work and interviews, it can be inferred that the population structure of such families is relatively simple. It is possible that pure peasant households comprise disadvantaged groups, such as the elderly, who are supported by the government in the process of relocation (Li, 2015). It is also possible that couples jointly carry out small-scale farming and have the necessary farming technology, so they can more readily adapt if they must relocate or resettle.

China currently provides 'compensation based on loss': monetary compensation is offered only for quantifiable loss, and it is difficult to make up for non-monetary loss, such as job opportunities and land pension value (Yan et al., 2018). Therefore, families that have low labour skills and rely on the original production environment need extra attention during relocation. Governments also need to introduce special policies after

relocation, such as skills training, labour transfer and welfare security, to help RAFs transform or upgrade their livelihood strategies.

By comparing the actual data with the standard distribution data, we can see that the livelihood resilience of households that resettle near the village is relatively high (Table S5 in the online supplementary materials). This shows that the social and economic environment of these families changed little (Wang, 2012). Their normal production, life and development were little affected, and they can seize the opportunity to improve their living standards. Most RAFs that choose long-distance relocation or a highly urbanized area have higher adaptability. Although livelihood capital is depleted in the process of relocation, these families have the ability to adapt to the production mode and development rate of the resettlement site. This finding shows that RAFs' choice of area of resettlement is based on not only the actual environmental capacity but also their future development needs. It can also be inferred that although livelihood resilience is a characteristic of the family itself, it is catalyzed by the external environment (Bui & Schreinemachers, 2011). That is, adaptability is affected by the different socio-economic environments, infrastructure levels and development opportunities of local agricultural and non-agricultural areas. Therefore, the government needs to pay attention to the improvement of infrastructure and social welfare when building new resettlement sites.

These observations confirm that livelihood resilience is not positively correlated with high non-agricultural income, highly urbanized resettlement area or high income. Therefore, livelihood resilience is an attribute of RAFs, representing the potential of development, rather than the 'wealth'. Ulanowicz (1986) used information theory technology to quantify both essential attributes of a system: efficiency and resilience. 'Efficiency' refers to the organization and effective behaviour of a system. 'Resilience' means that the system has a flexible buffer space and various actions that enable it to face abnormal disturbances (Goerner et al., 2009). For the livelihood system of RAFs, efficiency means specialized input and high-level output, which can reflect the economic level of families. Resilience is not wealth but reserve capacity. Low-resilience families do not have backup programmes to cope with changes in livelihood. Therefore, this critical framework also explains why families with higher incomes in the original socio-economic environment are not necessarily more able than poorer families to cope with changes in livelihood strategies and losses of productive capital. The livelihood resilience of RAFs depends more on their development possibilities than on their wealth. Therefore, broadening income channels, especially increasing the proportion of non-agricultural income, can help RAFs optimize their livelihood structure and prepare for a shock or pressure from the external environment.

Which indicator has the most impact on livelihood resilience?

The 20 indicators were selected from a number of research results. The relationship between each indicator variable by itself and livelihood resilience is not clear. But by comparing the mean values of the variables in the four groups (from weak to strong: susceptible, recovering, resistant and transformation), we can confirm that 13 variables are positively correlated with livelihood resilience: physical capital, dependency ratio, satisfaction with production conditions, social trust, satisfaction with social security,

satisfaction with infrastructure, development opportunities, livelihood diversification, satisfaction with residential environment, opportunities for labour transfer, psychological acceptance, convenience of production and transportation, and satisfaction with community organization. These indicators are important for resisting shocks and adapting to the environment. In particular, physical capital has the greatest positive impact on livelihood resilience. There is substitution effect or complementary effect between physical capital and other capital (Guan et al., 2019). Therefore, high physical capital can provide a more flexible backup plan for RAFs to cope with the shock. At the same time, China's RAFs attach great importance to physical capital, and they regard the accumulation of physical capital as the primary task after relocation. The other seven variables showed a negative correlation with livelihood resilience: proportion of agricultural income, family size, education, income, natural capital, financial capital and social capital.

The relationships of dependency ratio and family size to livelihood resilience are contrary to the original hypothesis. The positive effect of the dependency ratio may be because the families in disadvantaged groups find it easier to recover because they have more policy assistance than families in more advantaged groups. A large family does not bring demographic dividends (Zhao, Xiao, et al., 2018) but makes livelihood adjustment harder. High natural capital and high social capital represent the high dependence of RAFs on agricultural production and the local social and cultural environments, so these families find it difficult to cope with resettlement (Gong et al., 2019). Financial capital represents borrowing capacity, so families with more financial capital may face more repayment pressure.

Neither income nor education seems to have much impact on livelihood resilience, which seems surprising. It can be inferred that the range of income and education among farmers in rural China is not large, and farmers' production activities are mainly affected by labour skills and subjective initiative. A high proportion of agricultural income is closely related to low household resilience. This shows that pure agricultural production activities bring low income and low labour production skills (Feng, 2012), and the ability of these families to cope with stressors is relatively low. Therefore, RAFs should be encouraged to optimize their production structure, improve production skills and expand non-agricultural production channels to ensure the stability of their income sources.

Research implications

Further analysis of the present research will help policy makers locate special groups and improve relevant policies before, during and after resettlement. Our results highlight that optimizing the production structure and protecting the physical capital of RAFs from loss will help improve families' resilience.

To optimize the production structure, policies need to be differentiated according to household characteristics. Before relocation, it is necessary to assess the livelihood resilience of the households and help vulnerable groups transform and upgrade their livelihoods. For example, measures can be taken to provide vocational skills training or public welfare posts for labourers and to protect the rights and welfare of the elderly and children (Takesada, 2009). It is necessary to compensate for workplace shutdowns and other problems caused by relocation to ensure continuity of income during the relocation period. After relocation, households must be helped to integrate into the new

resettlement area as soon as possible. Good community management and cultural atmosphere are very important, and these can be enhanced by encouraging the village collective to carry out industrial projects and broaden income channels.

To safeguard physical capital, we need to consider the importance of houses to Chinese farmers. The home is their primary investment, and the purpose of making money is to improve living conditions. RAFs spare no effort to build new houses, and the high cost of doing so affects their subsequent production and lifestyle. Therefore, compensation and assistance with physical capital, including housing, are conducive to rapid recovery and adaptation after relocation (Yan et al., 2017). In the future, we could build a system for the dynamic assessment of the livelihood resilience of RAFs, using real-time tracking and measuring relevant indicators, to propose solutions to the specific problems they face.

Limitations

In this study, seven indicators were selected to represent the three dimensions of LRIM model framework, and 20 indicators represent the predictive variables of discriminant analysis in the LRIM model. So, the selection of indicators and the determination of weights were subjective. Whether other indicators can more accurately represent the three dimensions has yet to be determined. The results may vary with the indicators selected. For example, we used income growth rate to represent livelihood recovery (Li, 2013), but self-reported well-being could be used instead (An, 2011). These two indicators represent recovery from objective and subjective perspectives, but we did not compare their classification results.

Family survey data are partly determined by people's memories and individual perceptions, and the measurement standards of each family are different. Future work could compare the accuracy of the classification results from different indicators to identify the indicators that more accurately represent the three dimensions of the LRIM model. Attention should also be paid to the impacts on the RAFs' livelihood of other external factors, such as policies and regulations (Manatunge et al., 2009; Pan, 2018; Sunardi et al., 2013), the livelihood activities and cultural customs of the original inhabitants of the resettlement area (Geng & Chen, 2015), and the development rate and connectivity of the community (Wang, 2017). For example, different resettlement methods correspond to different forms of land compensation and financial compensation, and policy differences affect the speed of livelihood restoration in the short term; differences in post-resettlement assistance planning and implementation across resettlement areas also significantly affect the supportive effect of investment funds on the RAFs' livelihood. Therefore, a sounder evaluation system may be built in future research.

Conclusion

This article analyzes and assesses the livelihood resilience of 234 reservoir-affected families using the livelihood resilience inference measurement model, and validates and explains the classification results of livelihood resilience according to family resources, livelihood capital, and satisfaction with resettlement sites. Through *k*-means clustering, we find that most resettled families in the study area can be classified as 'recovering'.

Various classification criteria give significantly different results for livelihood resilience among and within different types of households. Livelihood strategy and area of resettlement also have an impact on livelihood resilience. The results of the discriminant analysis and the *k*-means clustering match well (87.2%), so the classification results are verified. We find that 20 variables can predict livelihood resilience with high accuracy, and four have the most significant impact: proportion of agricultural income, physical capital, dependency ratio, and satisfaction with the production conditions of the resettlement site. The following four points summarize this research.

(1) We considered the livelihood resilience of RAFs in terms of vulnerability when facing relocation and adaptability after relocation, which is an attribute of families and represents potential of development rather than wealth.
(2) The LRIM model was built and used for the first time to assess the livelihood resilience of RAFs. As a method of quantitative analysis, the LRIM model includes the process of validating and inferring, and is objective and accurate.
(3) Livelihood strategy and area of resettlement are not simply positively correlated with livelihood resilience. However, most of the second type of part-time farmers and those who resettled near the village had strong livelihood resilience. And a high proportion of agricultural income is strongly correlated with low resilience. Therefore, RAFs should be encouraged to improve their production skills and expand their non-agricultural production channels, and policy makers should pay attention to the optimization of the livelihood structure and the protection of physical assets.
(4) Although different water conservancy projects have their particularities, the indicators of family resources and external socio-economic environments extracted in this article can be used to analyze the livelihood resilience of affected families associated with various projects. The LRIM model is useful for predicting and improving the livelihood resilience of more affected families following reservoir construction.

Due to the limited data availability, the LRIM model built in this article has shortcomings, such as a lack of comprehensive indicators and weak representation of some indicators. Future research should establish a more comprehensive indicator system including local policies and institutions, and focus on determining more objective and accurate weights, to make timely, reasonable and effective suggestions for resettlement plans and policies.

Disclosure statement

The authors declare no conflict of interest.

Funding

There is no fund support for this study.

ORCID

Ruilian Zhang http://orcid.org/0000-0001-5064-1226

References

Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Ainuddin, S., & Routray, J. K. (2012). Institutional framework, key stakeholders, and community preparedness for earthquake induced disaster management in Balochistan. *Disaster Prevention and Management*, *21*(1), 22–36. https://doi.org/10.1108/09653561211202683

An, C. M. (2011). *Study on the well-being of rural residents in Jilin Province*. Jilin University (in Chinese).

Brand, F. S., & Jax, K. (2007). Focusing the meaning(s) of resilience: Resilience as a descriptive concept and a boundary object. *Ecology & Society*, *12*(1), 181–194. https://doi.org/10.2751/175303707X207963

Brooks, N., Adger, W. N., & Kelly, P. M. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change*, *15*(2), 151–163. https://doi.org/10.1016/j.gloenvcha.2004.12.006

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W. A., & von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra*, *19*(4), 733–752. https://doi.org/10.1193/1.1623497

Bui, T. M. H., & Schreinemachers, P. (2011). Resettling farm households in Northwestern Vietnam: Livelihood change and adaptation. *International Journal of Water Resources Development*, *27*(4), 769–785. https://doi.org/10.1080/07900627.2011.593116

Cai, J. L., Kummu, M., Niva, V., Guillaume, J. H. A., & Varis, O. (2018). Exposure and resilience of China's cities to floods and droughts: A double-edged sword. *International Journal of Water Resources Development*, *34*(4), 547–565. https://doi.org/10.1080/07900627.2017.1353411

Camilo, S. (2007). The impact of flood hazards on local employment. *Applied Economics Letters*, *14*(15), 1123–1126. https://doi.org/10.1080/13504850600606026

Chambers, R., & Conway, G. (1992). *Sustainable rural livelihoods: Practical concepts for the 21st century*. IDS Discussion Paper 296. Institute of Development Studies, Brighton. https://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/775/Dp296.pdf?sequence=1

Chang, S. E., & Shinozuka, M. (2004). Measuring improvements in the disaster resilience of communities. *Earthquake Spectra*, *20*(3), 739–755. https://doi.org/10.1193/1.1775796

Cumming, G. S., Barnes, G., Perz, S., Schmink, M., Sieving, K. E., Southworth, J., Binford, M., Holt, R. D., Stickler, C., & Van Holt, T. (2005). An exploratory framework for the empirical measurement of resilience: Surrogates for resilience of social-ecological systems. *Ecosystems*, *8*(8), 975–987. https://doi.org/10.1007/s10021-005-0129-z

Du, Y. S., & Li, F. (2014). Resettlement strategy for rural reservoir resettlement in the context of urbanization. *Rural Economy*, *20*(6), 109–112 (in Chinese).

Duan, Y. F., & Zhao, C. F. (2016). Reservoir resettlement urbanization resettlement model: Basic elements, institutional barriers and institutional arrangements. *Journal of China Three Gorges University (Humanities and Social Sciences Edition)*, *38*(1), 14–18 (in Chinese).

Fan, Q. X., Lu, Y. M., Qiang, M. S., & Wang, H. H. 2015. Research on the resettlement methods of China's hydropower development reservoirs from the perspective of sustainable development. *Journal of Hydroelectric Engineering, 34*(1), 237–244 (in Chinese).

Fang, Y.-P., Zhu, F.-B., Qiu, X., & Zhao, S. (2018). Effects of natural disasters on livelihood resilience of rural residents in Sichuan. *Habitat International*, *76*(6), 19–28. https://doi.org/10.1016/j.habitatint.2018.05.004

Feng, X. P. (2012). *Study on the risk and differentiation of landless farmers in the process of city merchandising*. Central China Normal University (in Chinese).

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. *Ambio: A Journal of the Human Environment*, *31*(5), 437–440. https://doi.org/10.1579/0044-7447-31.5.437

Food and Agriculture Organization of the United Nations. (2013a). *Resilient livelihoods-disaster risk reduction for food and nutrition security framework programme*. http://www.fao.org/3/a-i3270e.pdf

Food and Agriculture Organization of theUnited Nations. (2013b). *Disaster risk reduction: Strengthening livelihood resilience*. http://www.fao. org/docrep/018/i3325e/i3325e15.pdf

Geng, Y. H., & Chen, A. J. (2015). Resettlement of water conservancy and hydropower projects in minority areas. *Journal of Hohai University (Philosophy and Social Sciences Edition)*, *17*(1), 42–47 +90-91 (in Chinese).

Goerner, S. J., Lietaer, B., & Ulanowicz, R. E. (2009). Quantifying economic sustainability: Implications for free-enterprise theory, policy and practice. *Ecological Economics*, *69*(1), 76–81. https://doi.org/10.1016/j.ecolecon.2009.07.018

Gong, Y. C., Yao, K. W., Zhang, D., & Zhu, D. D. (2019). Research on family expenditure poverty of reservoir immigrants. *Water Power 45*(9), 6–11 (in Chinese).

Guan, R., Wang, W. L., & Yu, J. (2019). The impact of endogenous motivation on household income under the framework of sustainable livelihood. *Journal of Northwest Agricultural and Forestry University of Science and Technology (Social Science Edition), 19*(6), 130–139.

Han, W. J. (2016). *Research on vocational training of migrant workers in the process of urbanization with Chinese characteristics*. Shandong University (in Chinese).

Hartigan, J. A., & Wong, M. A. (1979). A K-means clustering algorithm. *Journal of the Royal Statistical Society, Series C (Applied Statistics)*, *28*(1), 100–108. https://doi.org/10.2307/2346830

He, J. J. (2014). *Study on reconstruction of livelihood ability of water conservancy project immigrants*. Wuhan University (in Chinese).

Heng, C., Lam, N. S. N., Yi, Q., Lei, Z., Correll, R. M., & Volodymyr, M. (2018). A synthesis of disaster resilience measurement methods and indices. *International Journal of Disaster Risk Reduction*, *31* (10), 844–855. https://doi.org/10.1016/j.ijdrr.2018.07.015

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology & Systematics*, *4*(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

Ingrisch, J., & Bahn, M. (2018). Towards a comparable quantification of resilience. *Trends in Ecology & Evolution*, *33*(4), 251–259. https://doi.org/10.1016/j.tree.2018.01.013

Internal Displacement Monitoring Centre. (2013). *Global estimates 2012: People displaced by disasters*. https://www.internal-displacement.org/global-report/grid2020/

International Federation of Red Cross. (2012). *World disasters report 2012: Focus on forced migration and displacement*. https://www.ifrc.org/en/publications-and-reports/world-disasters-report/world-disasters-report/

Jones, L., & Tanner, T. (2017). 'Subjective resilience': Using perceptions to quantify household resilience to climate extremes and disasters. *Regional Environmental Change*, *17*(1), 229–243. https://doi.org/10.1007/s10113-016-0995-2

Karimi, S., & Taifur, W. D. (2013). Resettlement and development: A survey of two of Indonesia's Koto Panjang resettlement villages. *International Journal of Water Resources Development*, *29*(1), 35–49. https://doi.org/10.1080/07900627.2012.739539

Lam, S. N., Qiang, Y., Arenas, H., Brito, P., & Liu, K. B. (2015). Mapping and assessing coastal resilience in the Caribbean Region. *Cartography & Geographic Information Science*, *42*(4), 1–8. https://doi.org/10.1080/15230406.2015.1040999

Lam, S. N., Reams, M., Li, K., Li, C., & Mata, L. P. (2015). Measuring community resilience to coastal hazards along the northern Gulf of Mexico. *Natural Hazards Review*, *17*(1), 04015013. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000193

Li, J. Y. (2013). *Assessment of resilience after agricultural floods*. Hunan University of Science and Technology (in Chinese).

Li, X., Lam, N., Qiang, Y., Li, K., & Zheng, W. (2016). Measuring county resilience after the 2008 wenchuan earthquake. *International Journal of Disaster Risk Science*, *7*(4), 393–412. https://doi.org/10.1007/s13753-016-0109-2

Li, Y. B. (2015). *Research on the protection of the rights and interests of immigrants in water conservancy projects*. Lanzhou University (in Chinese).

Liu, W., Xu, J., & Li, J. (2018). A study on the living vulnerability of farmers moving from land to poverty alleviation in Southern Shaanxi. *Resource Science*, *40*(10), 2002–2014 (in Chinese).

Manatunge, J., Takesada, N., Miyata, S., & Herath, L. (2009). Livelihood rebuilding of dam-affected communities: Case studies from Sri Lanka and Indonesia. *International Journal of Water Resources Development*, *25*(3), 479–489. https://doi.org/10.1080/07900620902957928

Marchese, D., Reynolds, E., Bates, M. E., Morgan, H., Clark, S. S., & Linkov, I. (2018). Resilience and sustainability: Similarities and differences in environmental management applications. *Science of the Total Environment*, *613-614* (Feb. 1), 1275–1283. https://doi.org/10.1016/j.scitotenv.2017.09.086

Marschke, M. J., & Berkes, F. (2006). Exploring strategies that build livelihood resilience: A case from Cambodia. *Ecology & Society*, *11*(1), 709–723. https://doi.org/10.1016/j.ecolecon.2005.06.002

National Research Council. (2012). *Disaster resilience: A national imperative*. National Academies Press.

Nyamwanza, A. M. (2012). Livelihood resilience and adaptive capacity: A critical conceptual review: Original research. *Jàmbá: Journal of Disaster Risk Studies*, *4*(1), 1–6. https://doi.org/10.4102/jamba.v4i1.55

Pan, L. D. (2018). *Resettlement of Songhuaba reservoir in Kunming*. Yunnan University of Finance and Economics (in Chinese).

Peng, S. P., Shi, G. Q., & Zhang, R. L. (2019). Social stability risk assessment: Status, trends and prospects —a case of land acquisition and resettlement in the hydropower sector. *Impact Assessment and Project Appraisal*. https://doi.org/10.1080/14615517.2019.1706386

Perreault, W. D., Behrman, D. N., & Armstrong, G. M. (1979). Alternative approaches for interpretation of multiple discriminant analysis in marketing research. *Journal of Business Research*, *7*(2), 151–173. https://doi.org/10.1016/0148-2963(79)90004-3

Quandt, A. (2018). Measuring livelihood resilience: The household livelihood resilience approach (HLRA). *World Development*, *107*(2), 253–263. https://doi.org/10.1016/j.worlddev.2018.02.024

Sallu, S. M., Twyman, C., & Stringer, L. C. (2010). Resilient or vulnerable livelihoods? assessing livelihood dynamics and trajectories in rural Botswana. *Ecology & Society*, *15*(4), 299–305. https://doi.org/10.1890/08-2244.1

Sina, D., Chang-Richards, A. Y., Wilkinson, S., & Potangaroa, R. (2019). A conceptual framework for measuring livelihood resilience: Relocation experience from Aceh, Indonesia. *World Development*, *117*(5), 253–265. https://doi.org/10.1016/j.worlddev.2019.01.003

Sok, S., & Yu, X. J. (2015). Adaptation, resilience and sustainable livelihoods in the communities of the Lower Mekong Basin, Cambodia. *International Journal of Water Resources Development*, *31*(4), 575–588. https://doi.org/10.1080/07900627.2015.1012659

Speranza, C. I., Wiesmann, U., & Rist,S. (2014). An indicator framework for assessing livelihood resilience in the context of social–ecological dynamics. *Global Environmental Change*, *28*(9), 109–119. https://doi.org/10.1016/j.gloenvcha.2014.06.005

Sunardi, B., Manatunge, J., & Pratiwi, F. D. (2013). Livelihood status of resettlers affected by the Saguling Dam project, 25 years after inundation. *International Journal of Water Resources Development*, *29*(1), 25–34. https://doi.org/10.1080/07900627.2012.738593

Takesada, N. (2009). Japanese experience of involuntary resettlement: Long-term consequences of resettlement for the construction of the Ikawa Dam. *International Journal of Water Resources Development*, *25*(3), 419–430. https://doi.org/10.1080/07900620902965459

Thulstrup, A. W. (2015). Livelihood resilience and adaptive capacity: Tracing changes in household access to capital in Central Vietnam. *World Development*, *74*(10), 352–362. https://doi.org/10.1016/j.worlddev.2015.05.019

Toole, S., Klocker, N., & Head, L. (2016). Re-thinking climate change adaptation and capacities at the household scale. *Climatic Change*, *135*(2), 203–209. https://doi.org/10.1007/s10584-015-1577-x

Ulanowicz, R. E. (1986). Growth and development: Ecosystems phenomenology. Springer: New York. https://doi.org/10.2307/1351721

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. https://sustainabledevelopment.un.org/post2015/transformingourworld

Walker, B. & Salt, D. (2006). *Resilience thinking. Sustaining ecosystems and people in a changing world*. Island Press..

Wang, Q. N. (2017). *Study on spatial characteristics and renaissance strategies of migration village of Gangnan reservoir*. Tianjin University (in Chinese).

Wang, Y. Z. (2012). *Research on key problems of survival and development of water project migrants based on complex system science*. Wuhan University of Technology (in Chinese).

Wilmsen, B., Adjartey, D., & Hulten, A. V. (2019). Challenging the risks-based model of involuntary resettlement using evidence from the Bui Dam, Ghana. *International Journal of Water Resources Development*, *35*(4), 682–700. https://doi.org/10.1080/07900627.2018.1471390

Yan, D. C., Shi, G. Q., Hu, Z. J., & Wang, H. B. (2017). Resettlement for the Danjiangkou Dam heightening project in China: Planning, implementation and effects. *International Journal of Water Resources Development*, *33*(4), 609–627. https://doi.org/10.1080/07900627.2016.1216829

Yan, D. C., Shi, G. Q., & Yi, Q. S. (2011). The impact of reservoir construction on the sustainable livelihood of migrants and the reconstruction path. *Water Resources Development Research*, 11(6), 49-53 (in Chinese).

Yan, D. C., Wang, M., Wang, H. B., & Shi, G. Q. (2018). Policy and implementation of land-based resettlement in China (1949–2014). *International Journal of Water Resources Development*, *34*(3), 453–471. https://doi.org/10.1080/07900627.2017.1417824

Zhao, X., Tian, Y., & Duan, Y. F. (2018). Research on the interventional poverty problem of reservoir migrants from the perspective of dual social change. *Agricultural Economic Issues*, 20(3), 108–118 (in Chinese).

Zhao, X., Xiao, J. Q., & Duan, Y. F. (2018). Resettlement, land transfer and transition of reservoir immigrant livelihoods. *Resources Science*, *40*(10), 1954–1965 (in Chinese).