frontiers | Frontiers in Environmental Science

ORIGINAL RESEARCH
published: 20 April 2022
doi: 10.3389/fenvs.2022.887988

Mixed Land Uses and Community Decline: Opportunities and Challenges for Mitigating Residential Vacancy in Peri-Urban Villages of China

Wenqiu Ma[1], *Guanghui Jiang*[2,3]*, *Tao Zhou*[3] *and Ruijuan Zhang*[4]

[1]College of Engineering, China Agricultural University, Beijing, China, [2]State Key Laboratory of Earth Surface Process and Resource Ecology, Beijing Normal University, Beijing, China, [3]Faculty of Geographical Science, College of Resources Science and Technology, Beijing Normal University, Beijing, China, [4]Beijing Land and Space Big Data Center, Beijing Municipal Commission of Planning and Natural Resource, Beijing, China

Residential vacancy is a visible symptom of community decline in peri-urban villages of China. Mixed-use development has emerged as a possible approach for land use planning to help mitigate community decline and residential vacancy. By applying an integrated framework, this study explores whether mixed land use (MLU) can help counter residential vacancy based on the classification of four types of peri-urban villages. Results show that the degree of MLU and residential vacancy rate both present increasing tendencies. Also, impacts of MLU on residential vacancy differ across villages: the disorderly and excessive mixed uses in some villages exacerbated residential vacancy, even threatening the neighborhood safety and livability; whereas for some villages with compatible mixed uses, the land use pattern could assist in reducing the residential vacancy, as well as promoting the compact and high-density development. Undeniably, planning for the increased mixed-use environment like urban communities is unsuitable for rural communities. Sustainable planning to counter residential vacancy should combine the compatible mixed-use development together with the rational functional zoning, which is also considered a constructive tool in mitigating community decline, and bringing human settlements development, vitality, and diversity. This research contributes to reconcile residential vacancy in the depopulating and declining communities.

Keywords: mixed land uses, community decline, residential vacancy, impacts, sustainability planning

OPEN ACCESS

Edited by:
Yanbo Qu,
Shandong University of Finance and Economics, China

Reviewed by:
Yanan Li,
University of Shanghai for Science and Technology, China
Guan Xiaoke,
Zhengzhou University of Light Industry, China
Claire Pan,
Cornell University, United States

***Correspondence:**
Guanghui Jiang
macrophage@126.com

Specialty section:
This article was submitted to Land Use Dynamics, a section of the journal Frontiers in Environmental Science

Received: *02 March 2022*
Accepted: *21 March 2022*
Published: *20 April 2022*

Citation:
Ma W, Jiang G, Zhou T and Zhang R (2022) Mixed Land Uses and Community Decline: Opportunities and Challenges for Mitigating Residential Vacancy in Peri-Urban Villages of China. Front. Environ. Sci. 10:887988. doi: 10.3389/fenvs.2022.887988

1 INTRODUCTION

Rural communities, the areas where rural residents live and produce (Yang et al., 2015; Ma et al., 2018a), are facing various global challenges, such as, depopulation, economic decline, unemployment, poverty, housing vacancy, and land abandonment. Mixed land uses (MLU) is one of the crucial indicators for land use development pattern and also is usually regarded as being desirable for building a livable and healthy community (Niemira, 2007; Herndon, 2011; Robledano-Aymerich et al., 2014; Nabil and Eldayem, 2015; Sahu, 2018; Motieyana and Azmoodeh, 2021). Whether mixed uses can be a basic element to achieve compact and sustainable planning in rural communities has been a crucial issue for rural development.

The idea of MLU was derived from the mixture of residential and non-residential activities in Roman cities (Zhuo et al., 2019). Then, with rapid urbanization and urban population growth over

the globe, relentless urban sprawl and the obsessively strict division of land uses by zoning have resulted in numerous unwanted influence for human society, such as urban traffic jam, the decay of city centers, and social isolations (Fainstein, 2005; Karen. et al., 2012; Song et al., 2013). Therefore, the Congress of New Urbanism (2001) and the Smart Growth Network (2006) promoted the closer integration of residential, commercial, and recreational uses. They claimed that compact, smart land use, complementary function, and mixed-use planning policies are essential for building sustainable cities (Musakwa and Niekerk, 2013; Jacobs-Crisioni et al., 2014). MLU, however, is also accompanied by some negative effects. For instance, the externalities of industrial land use always have significant impacts on residential use and values (Burnell, 1985; Tian et al., 2017). Cozens (2015) and Sohn (2016) claimed that mixed uses could adversely affect community safety. Whether advocating or opposing the idea, MLU is a controversial matter for many researchers.

In fact, this concept has expanded rapidly with many other aspects having been encompassed up to now. Since the 1970s, the vigorous development of rural economy has changed the economic activities dominated by agricultural production in developed areas and transformed the rural economy into a comprehensive economic structure involving agriculture, industry, commerce, and tourism (Kruska et al., 2003; Holmes, 2006; Ma et al., 2019). In addition, there has existed a natural tendency of mixing of land uses for human settlements in rural areas (Raman and Roy, 2019). Classifying rural communities following land use types, such as residential, commercial, and industrial, is an established strategy of rural planning (Ma et al., 2018b). One such example is China's peri-urban areas, where rural communities are mixed with a great diversity of landscapes (Leaf, 2002; Fan et al., 2015). Mixed use pattern has provided diverse daily services and choices for local residents, such as retail shops, grocery stores, restaurants, etc. Compared to cities, however, these facilities in villages occupied less land and always mixed with residential houses or industrial factories to decrease space costs (Zhao et al., 2015; Zhou et al., 2016). During the past decade, a growing number of studies pay attention to the intermixed functions of rural community (Zhen et al., 2009; Wang and Li, 2011; Yuan et al., 2017). For instance, Zhang (2014) and Ma et al. (2018a) have found that land use functions within rural communities can be categorized into residential, production, and ecological functions from the perspective of land use multifunctionality. Zhang et al. (2019) characterizes the mixed use of residential and industrial land in villages. These studies have produced important views on MLU in rural communities.

Along with urban–rural transformation, many villages have already experienced significant depopulation, primarily due to urban–rural gaps. Consequentially, depopulating residential areas are sometimes characterized by high unemployment, poverty, as well as increased housing vacancy and land abandonment (Wiechmann and Pallagst, 2012; Gu et al., 2019; Pan et al., 2021). Residential vacancy, as a visible symptom of community decline, has been another critical issue in the countryside. Currently, there exist various forms of land abandonment and residential vacancy, including abandoned and vacant houses, abandonment of infrastructure, idle factories, and bare land(Li et al., 2014), which can be reflected on the area of vacant land within a rural community. These abandoned and vacant lands not only have declined the rural vitality but also have profound ecological effects on the lives of rural inhabitants, biodiversity, soil erosion, and carbon sequestration (Queiroz et al., 2014; Miguel et al., 2015). Revitalizing abandoned and vacant land is critical to ensuring the long-term sustainability of rural development.

Facing these problems, some scholars proposed a series of theories and practices, including strategic planning for countryside (Anne and Gertrud, 2016), the Rural Renaissance Project (Baker, 2010), and land consolidation (Pašakarnis and Maliene, 2010). Among them, Liu et al. (2009) stated that the continual population loss, as well as single land use structure easily led to the vacancy of housing function and functional abandonment, and this phenomenon can be defined as the "hollow villages". Several scholars have introduced smart growth policy to solve this issue, claiming that mixed-use zoning can help mitigate the effects of community decline for vacant or abandoned residential properties (Williams, 2005; Bramley and Power, 2009; Haas, 2012). Nonetheless, given the small-sized area of villages, the interference of residential and industrial use easily led to environmental degradation (Tian, 2015). Strict zoning regulations were, therefore, considered a more salutary planning concept than MLU (An et al., 2018; Liu et al., 2019).

In spite of growing research interests on the MLU and rural residential vacancy resolution, studies on quantifying MLU and its impacts on rural residential vacancy have been fairly scarce. What are the impacts of mixed uses on community decline? Does mixed-use development effectively counter the residential vacancy? All of these questions should be further explored. Given the regional differentiation in Chinese villages in terms of geographical conditions, demographic structure, and industrial activities, the likely consequences of mixed-use development may differ across villages. Empirical analysis for its impacts can serve as a means of understanding whether MLU is beneficial for community decline and residential vacancy mitigation, and thus has significance for every strategy of human settlements. It could also provide feasible approaches to sustainable planning for rural transformation, renewal, and regeneration.

To achieve this, we attempt to analyze and compare the changing patterns of MLU and residential vacancy rate of rural community in various types of villages, and model the impacts of mixed uses on residential vacancy rate to determine whether MLU has a significant role on countering residential vacancy. Two issues should be addressed: (a) whether all mixed uses have favorable effects on rural compact development and (b) how can this information be used to mitigate residential vacancy in rural communities? This study continues with a comprehensive framework and the methods employed in the study, including measuring MLU and its relationship to vacant land. The findings then are described, demonstrating the spatiotemporal changing patterns of MLU and residential vacancy rate, respectively, and their relationship. The study

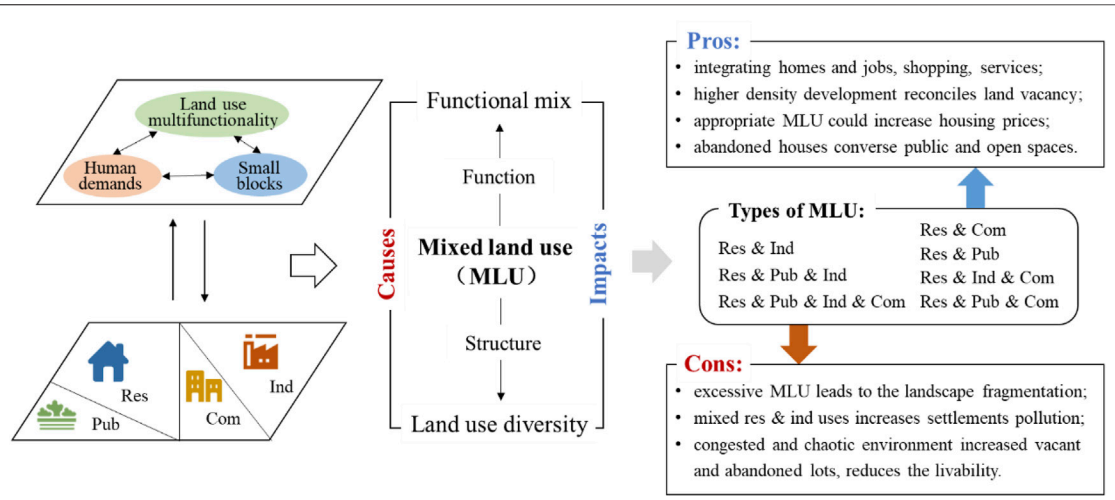

FIGURE 1 | Theoretical framework of MLU in rural communities. Notes: Res, Pub, Ind, and Com are abbreviations for residential land, public infrastructure land, industrial land, and commercial land, respectively.

also refers to a case study at the microlevel by using four typical villages, and vitalization strategies for community decline. The last section of this study summarizes the findings by referring to existing literature and the key implications for policy makers and researchers are highlighted.

2 THEORETICAL FRAMEWORK

2.1 What Is MLU in Rural Communities?

Atlanta Regional Commission (2011) has defined MLU as a type of land use pattern that blends different land-use types, which may be functionally integrated, and provide a sustainable development trend. There are four components of this concept: 1) different types of land uses/activities, 2) limited spatial range, 3) interaction and integration of these land uses/activities, and 4) a certain development goal, such as satisfying the multiple human demands, enhancing community vitality as well as promoting spatial allocation (Zhuo et al., 2019). MLU initially derived from urban communities (Williams, 2010; Jacobs-Crisioni et al., 2014); afterward, it was found in villages due to the rural multifunctionality (Holmes, 2006), especially in the peri-urban areas, where the frequent non-agricultural production and high-density residential activities have accelerated the possibility of land use conversion. Simultaneously, the small-sized villages would cause the interaction and overlapping of residential and non-residential spaces, thereby leading to a paradigm shift in practice from single-purpose partitioning to MLU (Tian et al., 2017; Zhang et al., 2019).

The MLU of rural communities could be defined as the mixture and interaction of multiple land uses covering residential, industrial, commercial, and recreational, that is, a series of land uses or activities within a rural community providing complementary functions. This phenomenon is more likely to happen in peri-urban areas and developed areas, where the diversification of the rural economy and livelihood has aroused the increasing demands for the land use multifunctionality comprising residence, non-agricultural production, recreation, etc., and mixed uses within rural communities can be regarded as the outcome of diverse land use choices to satisfy these demands (Cheng et al., 2017; Zhu et al., 2017). Consequentially, as discussed in **Figure 1**, land use multifunctionality and the limited spatial range of rural communities, are the underlying cause for the MLU; meanwhile, increasing demands from inhabitants for rural residential land functions can be identified as the proximate causes of MLU.

In the agricultural society of China, agricultural economic activities played a crucial role in rural communities, whose major function was to provide space for agricultural production and human settlements (William, 1964; Satsangi, 2007). Therefore, the rural community began with residential land mixing with a small number of public facilities in China, and residential function can be viewed as the primary and basic function in these areas. Afterward, along with the unprecedented process of industrialization and urbanization came the livelihood transition for farmers for residential land (Liu and Liu, 2016). Since then, the human–environment balance in the agricultural society has been broken, and more farmers were engaged in non-agricultural activities for both material and commercial purposes (Sharpley and Vass, 2006; Siciliano, 2012). As a consequence, there existed land use multifunctionality (including residence, industrial production, commercial service, leisure, recreation, etc.) and intermixed landscape within rural communities to meet these needs (DeFries et al., 2004; Ma et al., 2019). Mixed uses are commonly observed in the rural community, such as the mix of residential and commercial uses, mix of residential and industrial uses, mix of residential, and infrastructure uses. Simultaneously, since there were some other elements (e.g., physical geography conditions, economic location, and socioeconomic level) said to primarily determine the spatial

structure and the mixed use pattern within rural communities, MLU presented a remarkable spatial differentiation in China.

2.2 How MLU Affects the Residential Vacancy and Community Decline?

Over the last few decades, with rapid urbanization and economic growth, the rising socioeconomic inequality between rural and urban areas has become a major threat to China's development. Consequently, community decline was emerging over the countryside, reflecting in continual population loss, low-density sprawl, environmental pollution, and excessive vacant or abandoned houses (Long et al., 2012; Li et al., 2016; Han, 2017; Liu, 2018).

Among these problems, residential vacancy and land abandonment, as the results of human-environment systems degradation, have been urgent issues in rural areas (Khanal and Watanabe, 2006; Askland, 2018). It is widely agreed that MLU, as a key part of landscape patterns in rural communities, is correlated with land vacancy and abandonment (Zhao, 2013). However, the density and degree of mixing can ultimately result in varying impacts on rural residential vacancy. Therefore, it is essential to understand how MLU affects residential vacancy, and how a planner use the tool of mixed-use development to help rural residential land planning and public policy making.

A large amount of literature has offered empirical evidence that MLU can be a feasible alternative to create settlement patterns livable and sustainable (Duncan et al., 2010; Jacobs-Crisioni et al., 2014; Zhao et al., 2015). The benefits of MLU in rural communities can be categorized into two aspects: (1) multiple land uses can foster greater compact by integrating homes and jobs, shopping, services within small blocks, and therefore may assist in increasing interaction capabilities (Song and Knapp, 2004; Bao and Jiang, 2007). Ideally, it could also trigger higher density development through the provision of industries, services, and amenities, which, however, would escalate the risk of residential vacancy, industrial decline, infrastructure abandonment, and population loss in settlements with large numbers of abandoned buildings (Karen. et al., 2012; Gu et al., 2019). (2) The appropriate mixed-use development with residential and commercial components has the potential to raise land values. More importantly, the location of vacant land uses in mixed use zones has been shown to easily converse to community public land uses and open spaces (Cervero and Duncan, 2004; Han, 2014). This is a common phenomenon in organically developed villages and well-planned countryside.

Of course, MLU is also associated with some inherent challenges and problems. The opponents often claim that human settlements with higher mixed-use are likely to be more vulnerable to vacancy: 1) In general, it is suitable for one land parcel accommodating two or three types of land uses. Unfortunately, mixed uses, often based on small blocks where land suitable for development, are excessively complex and diverse in rural communities. This phenomenon not only leads to the fragmentation of landscape and functions, but also increases the difficulty of land use planning and regulation, thereby resulting in low-density development patterns with an excessive mix of residential, industrial, and commercial land uses a lack of adequate infrastructure, and increased vacant and abandoned lots (Keenan, et al., 1999; Sohn et al., 2012). 2) Different types of MLU will eventually produce different effects. As mentioned previously, mixing residential and commercial land uses has favorable effects on housing values, while larger ratios of industrial land use in human settlements tend to generate adverse spillover effects onto adjacent properties, such as lowering the value of tangent lots, and polluting the surrounding environment (Shultz and King, 2001; Taleshi and Bishehii, 2012). For most human settlements in China, as residential and industrial land occupied almost 80% of the total area, it is quite common for the mix of residential and industrial land use. In addition, Wang et al. (2014) found that this type of land use mix accompanied with the improper handling of mixed-use development caused the serious environmental pollution. Its negative externalities are highly concentrated around abandoned lots. This implies that the interference of industrial and residential land uses can easily lead to land abandonment, and then inevitably reduce the livability of human settlements. Such theoretical contradictions make it difficult to reach a conclusive agreement regarding how MLU effects rural residential vacancy. We can find that the level and degree of mixing, as well as the types of mixed uses (i.e., land use structure) determine the relationship between MLU and rural residential vacancy.

3 METHODOLOGY

3.1 Study Area

Pinggu District (40°02′- 40°22′N, 116°55′21″- 117°24′07″E) is a peri-urban district in the northeast of Beijing (the capital of China). The land area of Pinggu is 107,500 ha. The population was approximately 456 thousand according to the 2018 Pinggu Statistical Bureau. Its industrial sector mainly involves in the agricultural production, construction, production of metal products, garment processing, and tourism service. Pinggu District consists of 16 towns and 275 villages, and there are three area landform types: plains, mountainous, and semi-mountainous areas, each of which accounts for the 1/3 of the total region (**Figure 2**).

As land use pattern presents a remarkable spatial differentiation in various regions, a very broad and familiar classification of villages is based on the economic structure and GDP for various industries. This classification refers to the results of rural development assessments noted by Long et al. (2009) and Zhang and Zhang (2020), in terms of which we classify villages as agricultural production villages, industrial production villages, commercial agritourism villages, and comprehensive development villages. See details of classification in **Table 1**.

3.2 Data

Land use data of Pinggu in 2005 and 2018 used in this study were obtained from Google Maps. At the same time, accurate land

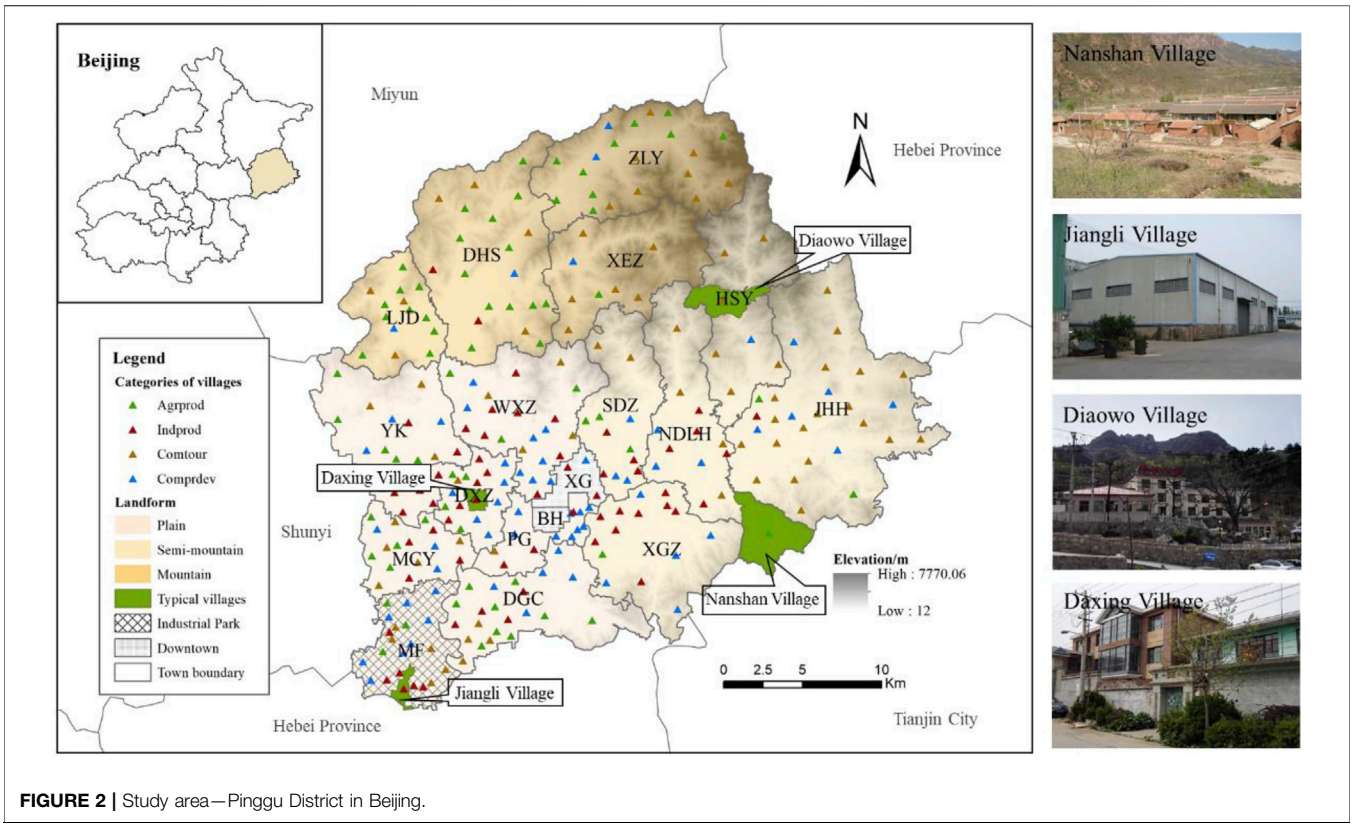

FIGURE 2 | Study area—Pinggu District in Beijing.

TABLE 1 | Classification of villages in Pinggu.

Categories	Abbrev	Criteria	Industrial Characteristics	The Number of Villages
Agricultural production village	Agrprod village	GDP 1% ≥ 31.95%	Producing food, feed, fiber, and many other desired products through cultivating certain plants Raising of domesticated animals (livestock)	72
Industrial production village	Indprod village	GDP 2% ≥ 60.49%	Manufacturing and processing production industries	61
Commercial agritourism village	Comtour village	GDP 3% ≥ 41.79%	Commerce, agritourism, recreational, and service industries	75
Comprehensive development village	Comprdev village	Exclusion for the above three types	Diversification of rural economy and industries	67

parcel information was obtained through image interpretation and practical survey. Then, according to the classification standard GDP J01-2013 of the geographical condition survey data, we identified vacant land as land cover characterized by waste, abandonment, idleness, and vacancy within rural communities.

Land use within rural communities refers to the lands for houses building, industrial production, construction for living needs, and necessary public facilities and infrastructure (Banski and Wesolowska, 2010). In China, there are five land-use types within rural communities: residential, industrial, commercial, public infrastructure, and vacant.

We also collected some socio-economic data from the 2005 and 2018 Statistical Yearbook, including gross output of industrial sectors, rural population, labor employment, etc. (Ma et al., 2018b). In addition, a household survey was conducted in collaboration with the head of the village, between October 2017 and January 2019 in Pinggu District. Household information includes household livelihood (such as farm and non-farm activities), income by source, and area of family houses (see **Table 4** for a detailed description of the variables and their quantification).

3.3 Methods

3.3.1 Measurement of MLU

As regards the definition of MLU, it refers to a heterogeneous pattern of land uses within an area, and usually involves the diversity of uses. MLU can be measured by a series of indices (Yoshida and Tanaka, 2005; Comer and Greene, 2015), including but not limited to spatial accessibility, entropy index, and

TABLE 2 | Measurement of mixed degree index.

Indices	Formulas	Explanation
Land-use richness	$0D = \sum_{i=1}^{N} p_i^0$	Designed for measuring species richness
Land-use randomness	$1D = \exp(-\sum_{i=1}^{N} p_i ln p_i)$	The exponential of Shannon entropy index
Land-use concentration	$2D = 1/\sum_{i=1}^{N} p_i^2$	This is the inverse of Simpson concentration. The superscript 2 on diversity (D) indicates that this is a second-order diversity
Mixed degree index	$D = 0D + 1D + 2D$	The higher value means the more degree of land use mix

dissimilarity index. However, the heterogeneous pattern of land use structure usually be neglected in these indices. Besides, in Chinese villages, residential land occupies an absolute dominant position, in contrast, other types of land use are almost negligible (Bordoloi et al., 2013). Therefore, we measured the degree and types of MLU by proposing two indices—mixed degree index and Weaver–Thomas index—which account for the extent to which complementary land uses adjoin one another—using only basic land use data.

1) Mixed degree index

We proposed a new mixed degree index—Hill Numbers—based on various existing parameters characterizing the degree of mixing, which mostly correlated to the land use interaction method (see **formula 1**). Conversion of some entropies such as the Shannon–Wiener and Gini–Simpson indices to the effective number of species is the key to a unified and intuitive interpretation of land use mix degree, including richness, randomness, and concentration (Manaugh and Kreider, 2013). Detailed analysis of land use mix degree quantification is given in **Table 2**.

$$^{q}D = \left(\sum_{i=1}^{N} p_i^q \right)^{1/(1-q)} \quad (1)$$

where p is the proportion of each land use type in rural settlements; N is the number of land uses. The exponent and superscript q can be called the "order" of the diversity, which depends only on the value in **Table 2**.

2) Weaver–Thomas index

In order to better identify the types of MLU, we adopted the Weaver–Thomas index (Marshall, 1892; Ma et al., 2018a). It can help explore the heterogynous pattern of MLU which cannot be characterized in the mixed degree index. Also, it can depict the types of MLU by analyzing the land use structure within rural communities.

3.3.2 Measurement of Residential Vacancy Rate

Residential vacancy is used as an indicator to measure community decline. The residential vacancy rate is the area vacancy rate of rural communities, which can be calculated by using the area proportions of vacant land within rural communities, as illustrated in **formula 2**.

$$VR = A_v / A, \quad (2)$$

where VR is the residential vacancy rate; A_v is the area of vacant land within a rural community; and A is the total area of the rural community.

3.3.3 Model Fitting

1) Variable design

According to the empirical studies, except for MLU, residential vacancy, as the visible symptom of rural community decline, is affected by other socioeconomic factors at the village level, such as location condition, population density, and non-agricultural gross value (Munroe et al., 2013; Newman and Bowman, 2018). More specifically, residential vacancy can be considered as the preferred outcome caused by rational choice of some farmers. For example, farmers who are engaged in non-farm activities in urban areas preferred to abandon their houses in the villages. Thus, some family characteristics such as income levels, household livelihood, and area of houses could affect the residential vacancy rate (Thorpe, 2018; Xu et al., 2019).

By reviewing existing research frameworks, MLU variables can be used to measure factors that affect vacancy rates. Residential vacancy rate was used as the dependent variable, and the MLU variable was used as independent variables. More importantly, the study fully considered influential household and village variables, two constructs of the independent variables were operationalized with the household family and village level characteristics. See Table 3 for detailed description of the variable design.

2) Hierarchical Linear Modeling

As shown in **Table 3**, these variables are usually hierarchical or multilevel (i.e., families are nested within villages), which means they cannot be explained by traditional regression models such as ordinary least squares (Raudenbush and Bryk, 2002). Therefore, we adopted hierarchical linear modeling (HLM), a two-level linear model of family and village variables, to explore the correlation between MLU and vacant land. This model is an extension of OLS, and it can take account of hierarchical data. Household family was the study unit for level-1, and village was the study unit for level-2. HLM combines variables at both layers and explains how the dependent variables are subjected to the influences of the first layer and second layer, respectively. The

TABLE 3 | Descriptive statistics of the variables used in the regression models.

Variable		Definition
Dependent variable	Residential vacancy rate	
Independent variables	**Level-1: Household family level**	
	Household income	
	Household livelihood	
	Full-time farming	Whether it is full-time farming (0 = no; 1 = yes)
	Part-time farming	Whether it is part-time farming (0 = no; 1 = yes)
	Non-farming	Whether it is non-farming (0 = no; 1 = yes)
	Area of family houses	
	Level-2: Village level	
	Terrain	
	Average elevation	
	Average slope	
	Spatial accessibility	
	Accessibility to roads	
	Accessibility to downtown	
	Per capita arable land	
	Population density	Rural resident population/total area of the village
	Growth rate of real GDP	Average growth rate of real GDP in the period
	Non-agricultural gross value	
	Non-agricultural employment	The number of labor in non-agricultural activities/total number of labor
	Adequate degree of infrastructure	The number of public infrastructures, such as schools, hospitals, libraries, etc.
	Villages compactness	Shape compactness = P^2/A P is the perimeter of the shape; A is the area of the shape
	Mixed land uses	Mixed degree index

final model for math achievement took the form of the following formulas:

$$\text{Level} - 1 \text{ Model} : Y_{ij} = \beta_{0j} + \beta_{1j} X_{ij} + \varepsilon_{ij} \quad (3)$$

$$\text{Level} - 2 \text{ Model} : \beta_{0j} = \gamma_{00} + \gamma_{01} W_{1j} + \mu_{0j} \quad (4)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} W_{1j} + \mu_{1j} \quad (5)$$

where i stands for farmer households; j stands for the village; X is the household family level variable; Y_{ij} is the dependent variable; β_{0j} and β_{1j} are the intercepts and slopes of unit j at the first layer, respectively; ε_{ij} is the random element of Y_{ij}; γ_{00} and γ_{10} are the average values for β_{0j} and β_{1j}, respectively, and their fixed components, which means that they are constant among the village variables; γ_{10} and γ_{11} are regression coefficients; W_{1j} is the first predictor variable at the village level; and μ_{0j} and μ_{1j} are random elements of β_{0j} and β_{1j}, respectively, representing the difference between village units.

4 RESULTS

4.1 Changing Patterns of MLU in Rural Communities

4.1.1 Land Use Change Within Rural Communities

Through surveys and data collection, we obtained the relevant statistics for the land use change within rural communities in Pinggu District. The gross land area of rural communities increased from 5918.53 ha in 2005–8090.8 ha in 2019. Furthermore, we measured its internal land use change (**Figure 3**). In general, residential function is often regarded as the primary and basic function in rural land use system. This phenomenon was relatively prominent in 2005 when residential land occupied the predominant position in residential areas. Whereas, it has been altered in the later period in which the proportions of all other land use types have been increased, especially for commercial land with the area proportion growing from 2.29% to 18.33%.

4.1.2 Spatiotemporal Changing Pattern of MLU in Rural Communities

Table 4 presents that the statistical results of mixed degree index, and it shows that the mixed degree index increased from 0.33 to 0.57 from 2005 to 2018. The increased index mainly suggested more about multiple land use structure, which changes from simple land use structure (such as single residential land, or mixed residential and industrial uses) to complex land use structure (such as mixed residential and commercial uses, mixed residential and public infrastructure uses, or mixed residential, industrial, and commercial uses).

Spatially, it is observed that the phenomenon of MLU was unremarkable in 2005; most areas presented the single residential land, and only the downtown area and the *Mafang Industrial Park* presented the mixed residential and industrial uses. In 2018, the areas with a high degree of MLU spread widely (see **Figure 4**), and the mixed degree index increased remarkably in plain and mountainous areas. On the one hand, under the influence of urbanization, what is likely to happen in plain areas was the prominent non-agricultural production and living service functions in urban-like human settlements, it was always accompanied by the MLU changing pattern from single residential land, mixed residential and industrial uses to mixed residential and commercial uses, as well as mixed residential, industrial, and commercial uses; on the other hand, MLU in the mountainous areas was occurring due to the booming of

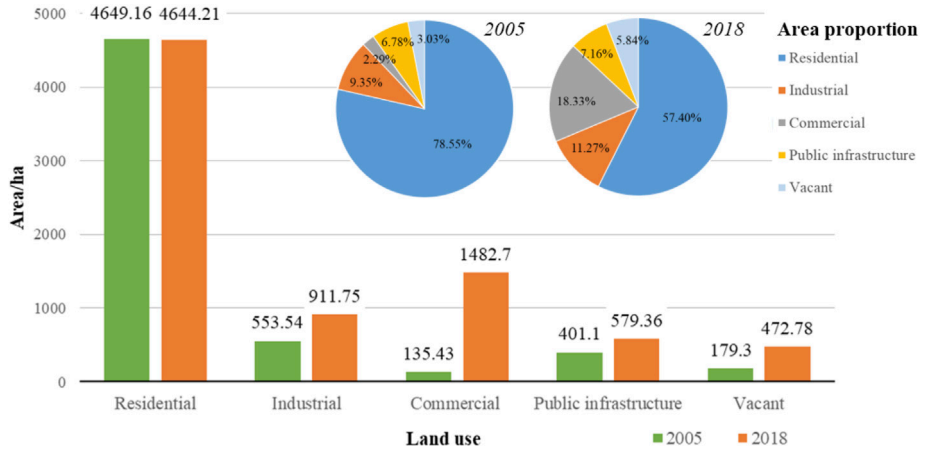

FIGURE 3 | Characteristics of internal land use change of rural communities from 2005 to 2018.

TABLE 4 | Characteristics of MLU and rural residential vacancy between 2005 and 2018.

Categories	Mixed Degree Index		Vacancy Rate	
	2005	2018	2005	2018
Agrprod village	0.15	0.33	0.028	0.012
Indprod village	0.30	0.51	0.031	0.0951
Comtour village	0.17	0.35	0.040	0.067
Comprdev village	0.28	0.45	0.033	0.111
Plain areas	0.21	0.42	0.041	0.085
Semi-mountainous areas	0.27	0.43	0.019	0.087
Mountainous areas	0.16	0.30	0.028	0.050
Total	0.33	0.57	0.030	0.058

agritourism (such as Jingdong Canyon and Jinhai Lake) have aroused some commercial, recreational, and leisure land uses.

At the village level, as shown in **Table 4**, the mixed degree in all types of villages has been enhanced greatly from 2005 to 2018, especially for agrprod and comtour villages where land use structure changed from residential land use to mixed residential and commercial uses. Moreover, the degree and types of MLU differ among village types, and the order is as follows: agrprod < comtour < indprod < comprdev. The reason behind this order is that the diversification of rural economy is often associated with the multiple land uses and high mixed degree in rural communities (Siciliano, 2012).

For agrprod villages, the self-sufficient economic status (including crop farming, planting, and breeding) and the lagging non-agricultural industrial development has constrained the multiple land uses. Its major function is merely to provide space for residential and simple public facilities service. In terms of comtour villages, they are endowed with numerous social, historic, and natural qualities. Consequently, aside from the land use pattern noted in agrprod villages, this type of village also has the potential to provide more recreational and tourism space, whereas the strict control of ecological environmental protection in the local region has altered the land use diversity and MLU. In indprod and comprdev villages, the prosperous industries, as well as the population agglomeration easily generated the land use multifunction (including recreation and leisure, residence, industrial and commercial production, public service, etc.), and multiple types of MLU have emerged, such as mixed residential and industrial uses; mixed residential, industrial and commercial uses; as well as mixed residential, industrial, commercial, and public infrastructure uses.

According to the above considerations and results, there are various factors influencing the MLU in rural communities, including economic locations, physical conditions, urban driving effects, and industrial structure. In general, along with the urbanization and industrialization process comes the more complex and multiple MLU. In this case, residential land is no longer the predominant land use. Also more and more inhabitants prefer the MLU to satisfy their diverse needs.

4.2 Changing Patterns of Residential Vacancy

From 2005 to 2018, the total area of vacant land changed from 179.3 to 472.78 ha, increased by 163.68%; meanwhile, vacancy rate increased from 0.03 to 0.058 (**Table 4**). Then, we identified the vacancy rate based on a comparative regional analysis. As discussed in **Figure 5**, in 2005, the vacancy rate in different regions ordered as plain areas > mountainous areas > semi-mountainous areas. The vacancy rate in plain areas (such as YK, DXZ, and MF) and northern mountainous areas (such as ZLY) is much higher. In 2018, the area of high vacancy rate enlarged, especially in some villages located in plain and semi-mountainous areas (such as JHH, SDZ, and NDL) where the suitable location and terrain provided a convenient foundation for the sprawl of rural build-up land, thereby, leading to the lack of the awareness of local residents for the importance of compact land use, and land use patterns became more fragmented. On the contrary, inferior geographical conditions and economic locations in mountainous areas were often accompanied by the insufficient land supply, and inhabitants preferred to put more effort into the

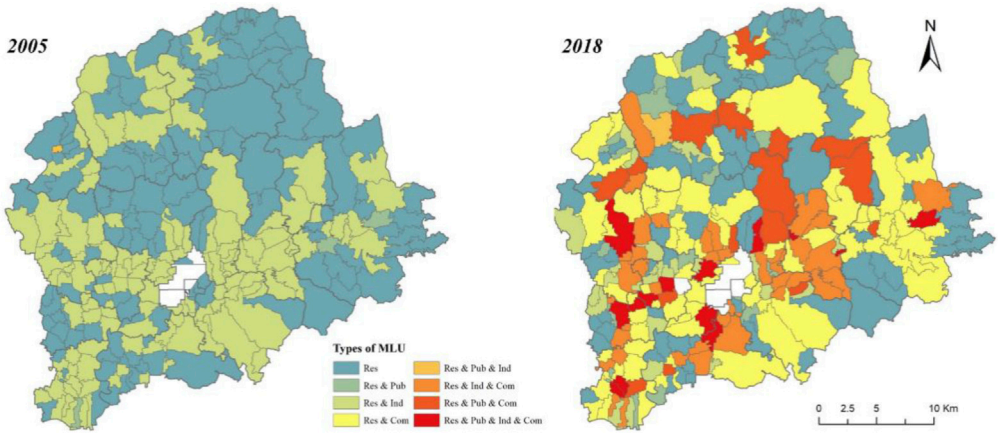

FIGURE 4 | Changing pattern of MLU in rural communities from 2005 to 2018.

shortfall of residential land. In addition, this area can be conceived as a slow-growing rural communities with relatively stable residents and low rates of land use conversion. Therefore, the compact and stable pattern decreased the vacancy rate of rural residential land.

For comparison with four categories of villages, it illustrated that there was no significant differentiation of vacancy rate in 2005; instead, the vacancy rate differed across the village types in 2018, showing as comprdev > indprod > comtour > agrprod. This tendency was consistent with the MLU. Compared with 2005, the residential vacancy rate grew remarkably among these villages except agrprod villages. In particular, residential vacancy rate in indprod and comtour villages increased 236.36 and 206.77%, respectively. In terms of indprod villages, the introduction of market economy has promoted the reorganization and restructure of enterprises to ensure the sustainable operation of rural industries. Consequently, some concentrated low-yield, polluting enterprises eventually closed down. These abandoned businesses and factories eventually transformed into vacant lots. For some comprdev villages, the income gap between urban and rural areas has forced more and more migrants moving to cities for economic and employment opportunities (Siciliano, 2012; Chen et al., 2014; Ma et al., 2018b). A large quantity of abandoned and vacant houses in villages can be characterized as the results of rural population loss.

4.3 Modeling the impacts of MLU on Residential Vacancy

MLU and rural residential vacancy are the two significant characteristics of paddy fields change in the study area, and we find a sharp increase in the residential vacancy rate and MLU in rural communities over the whole period from 2005 to 2018 in suburban areas of Beijing. As expected, the impacts of MLU on residential vacancy rate presented spatial non-stationarity. Moreover, as noted by Munroe et al. (2013), regardless of MLU, a number of factors showed association with residential vacancy, and their influences differed at the multilevel. Therefore, HLM and OLS analysis were used to explore the correlation between MLU and residential vacancy rate. **Table 5** presents the results of model fitting for the HLM with the reference values for the OLS. High *pseudo*-R^2 (McFadden's Adjusted) proved HLM to better explain the correlation between the MLU and residential vacancy rate.

As shown in **Table 5**, MLU in agrprod villages was non-significantly related to the increase of vacant land in any model; instead, some other variables like household livelihood, average elevation, per capita arable land, and adequate degree of infrastructure were found to be consistently significant in both models, and had negative signs ($p < 0.05$). According to the results in **Sections 4.1**, **4.2**, it revealed that values of mixed degree index and residential vacancy rate in this type of village were relatively low. Moreover, the changing patterns of MLU and residential vacancy rate were opposite. Although the MLU increased in the study period, the land used for production and living activities was limited, and farmers preferred the highly intensive land use pattern as a consequence. MLU has non-relationship with rural residential vacancy, and the vacant and abandoned land and others (such as bare land, and wild grassland) were mostly attributed by the adverse geographical conditions.

Based on the HLM, the MLU had a significant and positive sign ($p < 0.01$) in indprod villages, while the compactness had a negative sign, indicating that the residential vacancy is likely to happen in villages with higher MLU and low-density of land use pattern. At the village level, location conditions, adequate degree of infrastructure, and economic factors were significantly related to residential vacancy rate. The coefficients of these variables suggested that a higher residential vacancy rate was associated with a lower growth rate of real GDP and non-agricultural gross value, longer distance to roads, and inferior infrastructure construction. These results indicated that the MLU cannot cope with the traditional low-density development and sprawl patterns, with amounts of abandoned and vacant land, increased reliance on automobile travel, and the shortfall of adequate infrastructure. Because of the "orderly relocating all non-essential functions" implemented in 2015, indpro villages in the suburban area of Beijing have become the best places to supply land for undertaking

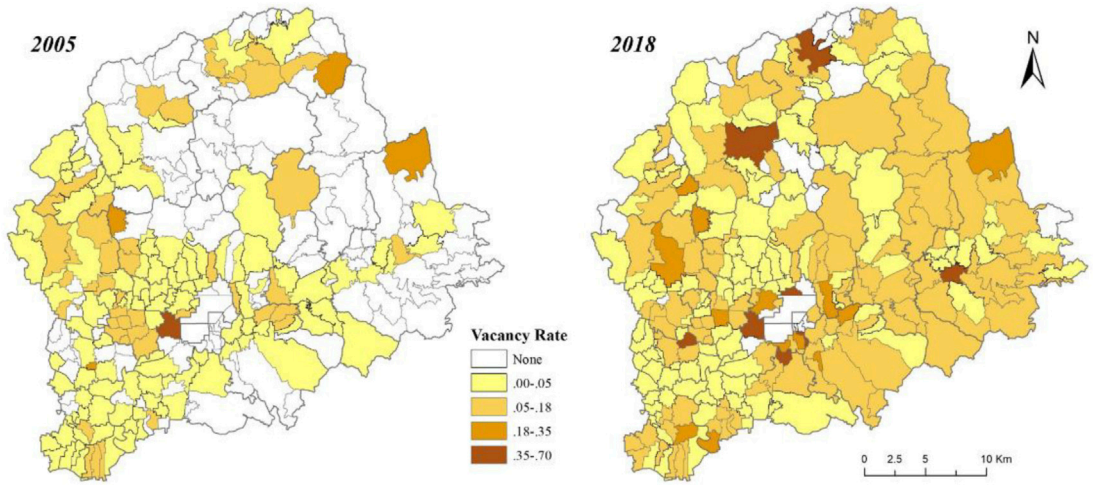

FIGURE 5 | Changing patterns of residential vacancy from 2005 to 2018.

TABLE 5 | Results of HLM and OLS analysis.

Variable	Agrprod Villages		Indprod Village		Comtour Village		Comprdev Village	
	HLM	OLS	HLM	OLS	HLM	OLS	HLM	OLS
Household family level								
Household income	-0.147	-0.153	0.372	0.373	-0.321***	-0.716***	0.658	0.658
Household livelihood								
Full-time farming	-0.429***	-0.566***	-0.318	-0.342	-0.641	-0.485	0.432	0.432
Part-time farming	0.145	0.121	0.394	0.348	-0.173***	-0.244***	0.267**	0.184**
Non-farming	0.729	0.645	0.479	0.479	0.523	0.404	0.579	0.521
Area of family houses	0.018	0.036	0.023	0.064	0.052	0.052	0.044**	0.029**
Village level								
Terrain								
Average elevation	-0.150***	-0.174***	-0.284	-0.461	-0.163	-0.332	0.271**	0.817**
Average slope	0.092	0.131	0.079*	0.079	0.104	0.106	0.082*	0.025
Spatial accessibility								
Accessibility to roads	0.977	0.849*	3.142**	4.358**	2.873*	2.967*	3.617	4.842
Accessibility to downtown	0.528	0.463	0.663	0.745	0.412	0.393	-0.364***	-0.161***
Per capita arable land	-0.474***	-0.474***	-0.523	-0.523	-0.484	-0.199	-0.846	-0.466
Population density	-0.038*	-0.049	-0.073	-0.045	-0.044	-0.031	-0.024***	-0.024***
Growth rate of real GDP	-0.053	-0.047	-0.022***	-0.048***	-0.068**	-0.054**	0.021	0.027
Non-agricultural gross value	0.079	0.079	0.037	0.021	-0.021**	-0.021**	0.058**	0.053**
Non-agricultural employment	0.615	0.615	-0.894***	-0.662***	0.567	0.293	0.779**	0.386**
Adequate degree of infrastructure	-7.852***	-8.366***	-6.424**	-6.424**	-6.386	-4.614	-4.438	-7.621
Villages compactness	-0.513	-0.664	-0.498***	-0.493***	-0.627	-0.844	-0.58**	-0.586**
Mixed land uses	-0.155	-0.213	0.329***	0.315***	-0.105**	-0.224**	0.179***	0.194***
N	72		61		75		67	
pseudo-R^2	0.388	0.387	0.425	0.379	0.442	0.414	0.341	0.293

*p < *0.1*. **p < *0.05*. ***p < *0.01, two-tailed test.*

these non-essential industries and enterprises. However, land use conflicts occurred between new and original industries because the industrial structure allocation in some villages was unsuitable for these exterior industries. Some approval but not built exterior industrial land as well as the outdated interior industrial land, therefore, caused amounts of factories abandonment and vacancy.

In terms of comtour villages, the MLU and residential vacancy rate presented the opposing relationship ($p < 0.01$), indicating that MLU had the potential to reduce the residential vacancy. This result is consistent with the findings of prior research (Zhao et al., 2015; Gu et al., 2019). Furthermore, variables like household income and part-time farming at the household family level ($p < 0.01$), as well as the growth rate of real GDP and non-agricultural industries gross value at the village level ($p < 0.05$) had significant and negative signs. Recently, the policy "beautiful countryside" and the agritourism booming forced some traditional villages with adequate infrastructure and prosperous economy to transform into comtour villages, together with the types of

MLU changing from mixed residential and public infrastructure uses to mixed residential and commercial uses. This changing pattern assisted in increasing the compatibility of MLU, which could not only guarantee the land use diversity but also help battle against rural residential decline over time.

MLU was also positively related to the residential vacancy in comprdev villages ($p < 0.01$), whereas the compactness of villages showed a negative sign ($p < 0.05$). The results were similar to that in indprod villages, revealing that MLU cannot effectively reduce the residential vacancy. At the household family level, the non-farming variable and the total area of houses variable were statistically significant ($p < 0.05$). At the village level, terrain variables had a negative relationship with residential vacancy rate ($p < 0.05$), suggesting that the residential vacancy easily occurred in the plain areas. Moreover, non-agricultural gross value and non-agricultural employment showed positive relationships with residential vacancy rate ($p < 0.01$). Also, the coefficients of the accessibility to downtown and population density variables suggested that a higher residential vacancy rate is associated with lower population density and longer distance to downtown ($p < 0.01$). Due to superior locational conditions, the inhabitants living in the suburban areas obtained accessibility to downtowns and cities to pursue livelihood improvement. This detachment between human and land under rural–urban migration has generated a growing number of abandoned houses and vacant land.

5 DISCUSSION

5.1 Why Do Impacts of MLU on Residential Vacancy Differ Across the Village Types? A Case Study of Four Typical Peri-Urban Villages

In order to better explore and verify the relationship between MLU on residential vacancy in different types of villages, we selected four typical villages by stratified sampling, including Nanshan Village, Jiangli Village, Diaowo Village, and Daxing Village (see in **Figure 1**). We used the participatory rural appraisal and field survey to obtain the internal spatial structure (**Figure 6**) and tried to explain why impacts of MLU on residential vacancy differ across the village types.

1) Agrprod village: Nanshan village

This village, located in the southeast of Pinggu District, is surrounded by mountains. The majority of the economically active population is engaged in agricultural production for both subsistence and commercial purposes. From 2005 to 2018, the value of mixed degree index increased from 0.043 to 0.132. Residential land was predominant in 2005, with the area proportion of 96.85%. It presented a scattered distribution to take full advantage of the convenient transportation and the limited plain terrain. In 2018, the area of land used for public facilities and infrastructure (such as roads, squares, hospitals, and schools) has increased by 38.91%, and the spatial structure presented the circling-layering land use layout pattern (**Figure 6**). Also, adequate infrastructure has beneficial in reducing the residential vacancy rate, and some vacant and abandoned land along with the roads has been used. Residential vacancy rate has decreased from 0.043 to 0.01. However, there still existed 73.55% of vacant land (such as bare land and wild grassland) in mountains hard to utilize, which also proved that MLU cannot be the effective resolution for reducing natural land abandonment.

2) Indprod village: Jiangli village

This village is located in the southern plain of Pinggu and is positioned in the center of MF. In 2018, its secondary industry output value reached to 92,915 thousand *yuan*, accounting for 89.31%. During the study period, lots of factories moved from the center city, such as textile mills, and electronics companies, which have aroused the area increase of industrial land (increased by 3632.21%). Also, the degree of MLU changed from 0.32 to 0.42. Spatially, these industrial land often sprawled along with the road networks, showing a centrifugal-radial land use changing pattern. Ultimately, a part of them agglomerated within *Mafang Industrial Park*, while others mixed with residential land.

The centrifugal-radial changing pattern, however, has broken the compact and orderly spatial layout in the village. For example, new and old houses, as well as interior and exterior factories sometimes led to chaotic and over-mixed residential and industrial uses. Moreover, these lands were at risk of being abandoned as a result of industrial pollution from adjacent enterprises. The absence of appropriate land use planning before the implementation of MLU and legal enforcement after the introduction of MLU might lead to illegal and abandoned non-residential activities in residential areas. Therefore, the residential vacancy rate of this village increased from 0.035 to 0.047.

3) Comtour village: Diaowo village

This village is located in the HSY Town, northeast of Pinggu. It is famous for the beautiful scenery such as Jiongdong Canyon, and the rich folk culture. Based on the statistic results, the gross output of primary and tertiary industry accounted for 34.93%, 63.23%, respectively. From 2005 to 2018, the degree of MLU increased from 0.49 to 0.60: residential and infrastructural land have composed the early living space within the village in 2005, with the area proportion of 52.52 and 32.06%, respectively; in 2018, some new types of MLU like mixed residential, commercial, and public infrastructure uses, were found as a result of industrial transformation from agriculture to commerce and agritourism. Spatially, the new commercial land presented a striped distribution between residential and public infrastructure land—the living space filled with productive space—showing a compact spatial pattern.

Meanwhile, the residential vacancy rate of this village decreased from 0.067 to 0.021, indicating that this compact pattern was conducive to reduce the residential vacancy and land abandonment. The main reason behind this change was the implementation of a "beautiful countryside" policy, including dismantling some "illegal" houses and factories, consolidating old villages, etc., all of which were helpful in achieving the smart growth of this village. Furthermore, the houses owning the mixed residential and commercial uses were easily rented, thus local inhabitants were

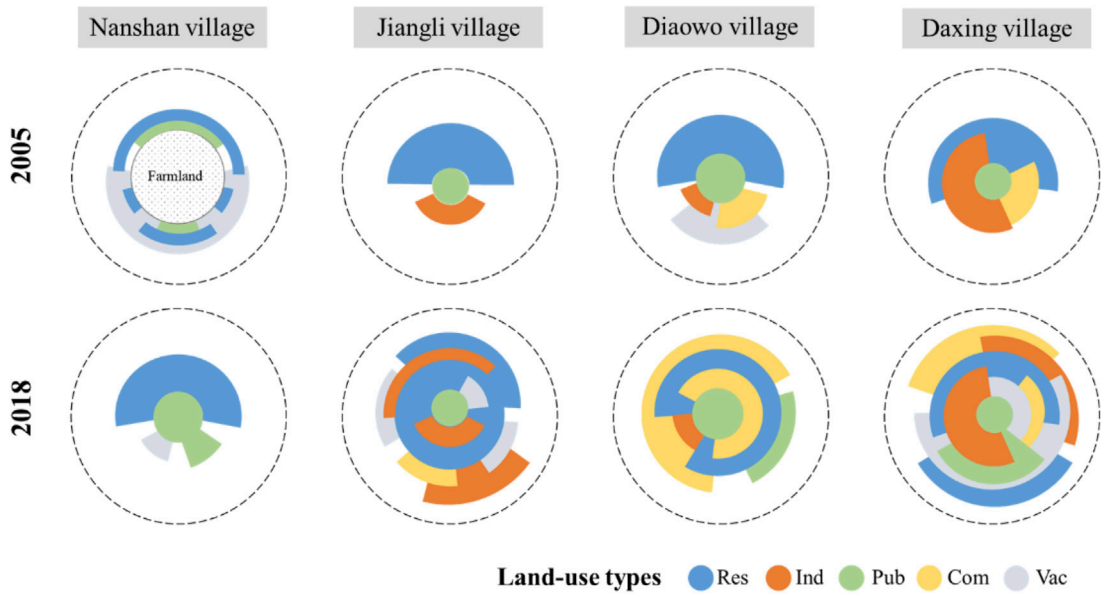

FIGURE 6 | Spatial structure of four typical villages.

inclined to utilize the vacant land around their houses to increase the economic benefits.

4) Comprdev village: Daxing village

This village is located in the urban–rural interface of Pinggu District. The diversification of the rural economy and industry (including agriculture, industry, and commerce) has been realized under the influence of urbanization process. The degree of MLU increased from 0.64 to 0.71 during the study period. It can be seen in **Figure 6** that in 2005, the compact land use layout pattern formed within the village with the mixed residential, industrial, and public infrastructure uses, where residential land was located in the center of the village, and other types of land distributed in the fringe of the village. Afterward, the diverse livelihood of inhabitants led to a more complex MLU, and some residential and industrial land were replaced and combined by commercial land.

Recently, one of the major threats for the village was residential vacancy and environmental degradation, and residential vacancy rate increased by 21.21%. The phenomenon was attributed to excessive and complex MLU. In particular, the inappropriate mix of residential, industrial, and commercial land would worsen the livability of the village. The majority of inhabitants, therefore, migrated to cities to pursue a high-quality lifestyle. The demographic census results illustrated that 51.48% of inhabitants had their own houses in the downtown. As a result, there emerged considerable rural houses being abandoned in the village.

5.2 Implications for Rural Community Sustainability Planning

Nowadays, the magnitude and the rapidity characterizing the urbanization process in the Chinese countryside have aroused the diversification and heterogeneity of rural community transformation, thereby resulting in the land use multifunctionality and mixed-use development. According to the previous considerations and results, some villages with MLU have high rates of residential vacancy and housing abandonment, which is questionable. Land use strategies that prioritize MLU, by placing residential, industrial, and commercial areas in close proximity, cannot always promote compact development and the efficient use of land. Whether functional zoning or mixed-use development, feasible approaches to land use planning are important for human settlements in decline. These findings bring potential implications for future sustainability planning in rural areas.

First, considering the spillovers of industrial pollution to adjacent residential spaces, it is necessary to separate the residential land from high-pollution industrial land and divide land uses in residential areas into industrial zones, residential zones, and recreational zones. This policy tool—functional zoning—could reconcile conflicts between industrial and residential land in ways that create livable and sustainable settlement patterns, as well as put idle factories and vacant industrial land to better use, which have potential to provide spatial support for rural industrial development and vitalization strategies.

Second, as MLU failed to reconcile the residential vacancy and houses abandonment, a combination of functional zoning and mixed-use development together with the introduction of marketing rural collective land programs may be a feasible alternative to compact development. The focus of land use planning in rural communities should sufficiently emphasize the orderliness and compatibility of land use patterns. When referring to the development and utilization of land, it is necessary to follow the principle—residential function takes precedence over the non-residential functions—which could solve the problem of "land use

function exceeding the village carrying capacity." Compatible and predicted MLU should rely on functional zoning.

Third, the vacant land utilization and consolidation should not only consider land suitability, but also refer to village functions and human demand. For example, some vacant land distributing as a striped pattern between residential and public infrastructure space should be exploited as green space (e.g., garden beds or green land) to enhance the livability and ecological function of human settlements. Moreover, some large-scale vacant land can be reserved as potential land resources for future village development. Additionally, lawful rural residential land property trading could guarantee abandoned houses and vacant land to be utilized legitimately.

With the advent of the 21st century, the coexistence of MLU and rural residential vacancy has been employed as one of the common phenomena, which occurs due to the process of industrialization and urbanization in rural China. Sometimes, the inclusion of MLU is considered as a carrier of compact development, and even resulting in community decline. All of these points are connected by a series of influences—primarily driven by the urban–rural gap. Indeed, functional zoning and mixed-use development should not contradict with each other. Considering the village characteristics, integrating mixed-use development into rational functional zoning is a useful and effective tool to achieve the rural sustainability planning.

5.3 Contribution to Research, Limitations, and Future Work

The link between MLU and regional compact development has been extensively researched in the field of urban studies. The advocates of MLU claim that the combination of the residential, industrial, and commercial uses can reduce neighborhood decline and community vacancy (Karen. et al., 2012; Gu et al., 2019). In contrast to those in urban studies, increased mixed-use environments in some Chinese rural areas may have adverse effects on the livability of settlements, even deteriorating the residential vacancy. Therefore, whether MLU is a feasible strategy for residential vacancy resolution is a critical issue in rural sustainability.

This study helps to understand the relationship between MLU and community decline, and reconcile residential vacancy in the countryside suffering rural depopulation. It brings together several separate areas of literature concerning MLU, spatial structure, and residential vacancy in rural areas, and opposes previous research findings that increased mixed-use planning is playing an important role in altering community decline. In addition, the introduction of HLM analysis, which takes into MLU, and other driving factors at the multilevel, provides a quantitative method to explore their correlation with rural residential vacancy. Also, this study presents implications concerning the effectiveness and feasibility of rural community sustainability planning policies drawn to build livable and healthy communities in rural areas.

When interpreting these results, some limitations of this study should be regarded. First, the pseudo R-square values (more than 0.3) for the two models were relatively low, and the HLM does not demonstrate the causation between the MLU and residential vacancy thoroughly. We will perform longitudinal analysis to examine causal relationships carefully. Second, because of the limitation of the database, the case study—Pinggu District in Beijing is relatively small. Future studies will use other cases for comparison to verify the conclusions in this study. It could provide a significance to wider a wider scientific community and lead to more feasible rural community sustainability planning.

6 CONCLUSION

By applying an integrated framework, this study has analyzed and compared the changes in MLU and residential vacancy in peri-urban areas. During the study period, the degree of MLU and residential vacancy rate both showed increasing tendency. Their changing patterns, however, differed across four types of village, which referred to the village with the complex MLU was often associated with the high residential vacancy rate. To account for this, a model approach was used to explore impacts of MLU on rural residential vacancy. The findings show a substantial difference among village types: the disorderly and excessive mixed uses in indprod and comprdev villages exacerbated residential vacancy, even threatening the neighborhood safety and livability, whereas compatible MLU in comtour villages assisted in reducing the residential vacancy rate, as well as promoting the compact and high-density land use pattern.

When it comes to prototyping residential vacancy solutions, it is important to understand and consider the major village characteristics in China. For most villages, although urbanization process arouses the MLU, land use change in rural communities remains as the traditional way of relentless sprawl. Undeniably, planning for increased mixed-use environment like urban land uses, according to this research, is unsuitable for rural communities. Sustainable planning to counter residential vacancy should combine the compatible mixed-use development together with the rational functional zoning, which can also be considered a constructive tool in mitigating community decline, as well as bringing human settlements development, vitality, and diversity.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

In this study, WM processed the data and wrote the main contents of the article. GJ, TZ and RZ provided ideas for the paper. All the authors discussed the results and implications and commented on the manuscript at various stages.

FUNDING

This work was supported by the National Natural Science Fund of China (Grant Nos. 42001199, 42071249), and the National Social Science Fund of China (20&ZD090).

REFERENCES

An, Y., Zhou, G., He, Y., Mao, K., and Tan, X. (2018). Research on eoretical framework of MLU in rural commu the Functional Zoning and Regulation of Rural Areas Based on the Production-Life-Ecological Function Perspective: a Case Study of Changsha-Zhuzhou-Xiangtan Area. *Geogr. Res.* 37 (4), 695–703. (in Chinese).

Anne, T., and Gertrud, J. (2016). Translating a Wicked Problem: a Strategic Planning Approach to Rural Shrinkage in Denmark. *Landsc. Urban Plann.* 154, 29–34.

Askland, H. H. (2018). A Dying Village: Mining and the Experiential Condition of Displacement. *Extractive Industries Soc.* 5, 230–236. doi:10.1016/j.exis.2018.02.007

Atlanta Regional Commission (2011). *Quality Growth Toolkit: Mixed-Use Development*. Atlanta Regional Commission.

Baker, J. A. (2010). A Rural Renaissance in America. *Am. J. Econ. Soc.* 24 (1), 84.

Banski, J., and Wesolowska, M. (2010). Transformations in Housing Construction in Rural Areas of Poland's Lublin Region Influence on the Spatial Settlement Structure and Landscape Aesthetics. *Landsc. Urban Plann.* 94, 116–126.

Bao, Q., and Jiang, Y. (2007). *The Mixed-Use and Development of CBD*. Urban Problems, 52–56. (in Chinese).

Bordoloi, R., Mote, A., Sarkar, P. P., and Mallikarjuna, C. (2013). Quantification of Land Use Diversity in the Context of Mixed Land Use. *Proced. - Soc. Behav. Sci.* 104, 563–572. doi:10.1016/j.sbspro.2013.11.150

Bramley, G., and Power, S. (2009). Urban Form and Social Sustainability: The Role of Density and Housing Type. *Environ. Plann. B Plann. Des.* 30-48. doi:10.1068/b33129

Burnell, J. D. (1985). Industrial Land Use, Externalities, and Residential Location. *Urban Stud.* 22, 399–408. doi:10.1080/00420988520080711

Cervero, R., and Duncan, M. (2004). Neighbourhood Composition and Residential Land Prices: Does Exclusion Raise or Lower Values? *Urban Stud.* 41, 299–315. doi:10.1080/0042098032000165262

Chen, R., Ye, C., Cai, Y., Xing, X., and Chen, Q. (2014). The Impact of Rural Out-Migration on Land Use Transition in China: Past, Present and Trend. *Land Use Policy* 40, 101–110. doi:10.1016/j.landusepol.2013.10.003

Cheng, Z., Cai, J., and Yang, Z. (2017). Spatial Reconstruction and Planning Response for Mixed Land Use in the Peri-Urban Area: A Case Study of Chengdu. *City Plann. Rev.* 41 (10), 53–59+67. (in Chinese).

Comer, D., and Greene, J. S. (2015). The Development and Application of a Land Use Diversity index for Oklahoma City, OK. *Appl. Geogr.* 60, 46–57. doi:10.1016/j.apgeog.2015.02.015

Congress of New Urbanism (2001). *Charter for the New Urbanism*. Chicago, Illinois: Congress for the New Urbanism.

Cozens, P. (2015). "Crime and Community Safety: Challenging the Design Consensus," in *The Routledge Handbook of Planning for Health and Well-Being*. Editors H. Barton, S. Thompson, S. Burgess, and M. Grant (London: Routledge).

DeFries, R. S., Foley, J. A., and Asner, G. P. (2004). Land-use Choices: Balancing Human Needs and Ecosystem Function. *Front. Ecol. Environ.* 2, 249–257. doi:10.1890/1540-9295(2004)002[0249:lcbhna]2.0.co;2

Duncan, M. J., Winkler, E., Sugiyama, T., Cerin, E., duToit, L., Leslie, E., et al. (2010). Relationships of Land Use Mix with Walking for Transport: Do Land Uses and Geographical Scale Matter? *J. Urban Health* 87 (5), 782–795. doi:10.1007/s11524-010-9488-7

Fainstein, S. S. (2005). Cities and Diversity. *Urban Aff. Rev.* 41, 3–19. doi:10.1177/1078087405278968

Fan, J., Heberer, T., and Taubmann, W. (2015). *Rural China: Economic and Social Change in the Late Twentieth Century*. London, U. K: Routledge.

Gu, D., Newman, G., Kim, J.-H., Park, Y., and Lee, J. (2019). Neighborhood Decline and Mixed Land Uses: Mitigating Housing Abandonment in Shrinking Cities. *Land Use Policy* 83, 505–511. doi:10.1016/j.landusepol.2019.02.033

Haas, T. (2012). *Sustainable Urbanism and beyond: Rethinking Cities for the Future*.

Han, H.-S. (2014). The Impact of Abandoned Properties on Nearby Property Values. *Housing Policy Debate* 24, 311–334. doi:10.1080/10511482.2013.832350

Han, H. (2017). Neighborhood Characteristics and Resistance to the Impacts of Housing Abandonment. *J. Urban Aff.* 1-24. doi:10.1080/07352166.2016.1262688

Herndon, J. (2011). *Mixed-Use Development in Theory and Practice: Learning from Atlanta's Mixed Experiences*. Georgia Institute of Technology.

Holmes, J. (2006). Impulses towards a Multifunctional Transition in Rural Australia: Gaps in the Research Agenda. *J. Rural Stud.* 22 (2), 142–160. doi:10.1016/j.jrurstud.2005.08.006

Jacobs-Crisioni, C., Rietveld, P., Koomen, E., and Tranos, E. (2014). Evaluating the Impact of Land-Use Density and Mix on Spatiotemporal Urban Activity Patterns: an Exploratory Study Using mobile Phone Data. *Environ. Plan. A.* 46 (11), 2769–2785. doi:10.1068/a130309p

Karen, C., Wallace, A., and Duffy, S. (2012). *The Influence of Land Use Mix, Density and Urban Design on Health: A Critical Literature Review*. University of York.

Keenan, P., Lowe, S., and Spencer, S. (1999). Housing Abandonment in Inner Cities-The Politics of Low Demand for Housing. *Housing Stud.* 14, 703–716. doi:10.1080/02673039982687

Kruska, R. L., Reid, R. S., Thornton, P. K., Henninger, N., and Kristjanson, P. M. (2003). Mapping Livestock-Oriented Agricultural Production Systems for the Developing World. *Agric. Syst.* 77, 39–63. doi:10.1016/s0308-521x(02)00085-9

Leaf, M. (2002). A Tale of Two Villages. *Cities* 19 (1), 23–31. doi:10.1016/s0264-2751(01)00043-9

Li, Y., Liu, Y., Long, H., and Cui, W. (2014). Community-based Rural Residential Land Consolidation and Allocation Can Help to Revitalize Hollowed Villages in Traditional Agricultural Areas of China: Evidence from Dancheng County, Henan Province. *Land Use Policy* 39, 188–198. doi:10.1016/j.landusepol.2014.02.016

Li, Y., Westlund, H., Zheng, X., and Liu, Y. (2016). Bottom-up Initiatives and Revival in the Face of Rural Decline: Case Studies from China and Sweden. *J. Rural Stud.* 47 (47), 506–513. doi:10.1016/j.jrurstud.2016.07.004

Liu, Y. (2018). Introduction to Land Use and Rural Sustainability in China. *Land Use Policy* 74, 1–4. doi:10.1016/j.landusepol.2018.01.032

Liu, Y., Li, T., Zhao, W., Wang, S., and Fu, B. (2019). Landscape Functional Zoning at a County Level Based on Ecosystem Services Bundle: Methods Comparison and Management Indication. *J. Environ. Manage.* 249, 109315. doi:10.1016/j.jenvman.2019.109315

Liu, Y., Liu, Y., and Zhai, R. (2009). Geographical Research and Optimizing Practice of Rural Hollowing in China. *Acta Geogr. Sin.* 64 (10), 1193–1202. (in Chinese).

Liu, Z., and Liu, L. (2016). Characteristics and Driving Factors of Rural Livelihood Transition in the East Coastal Region of China: a Case Study of Suburban Shanghai. *J. Rural Stud.* 43, 145–158. doi:10.1016/j.jrurstud.2015.12.008

Long, H., Li, Y., Liu, Y., Woods, M., and Zou, J. (2012). Accelerated Restructuring in Rural China Fueled by 'increasing vs. Decreasing Balance' Land-Use Policy for Dealing with Hollowed Villages. *Land Use Policy* 29, 11–22. doi:10.1016/j.landusepol.2011.04.003

Long, H., Liu, Y., and Zou, J. (20092009). Assessment of Rural Development Types and Their Rurality in Eastern Coastal China. *Acta Geogr. Sin.* 64 (4), 426–434.

Ma, W., Jiang, G., Li, W., and Zhou, T. (2018a). How Do Population Decline, Urban Sprawl and Industrial Transformation Impact Land Use Change in Rural Residential Areas? A Comparative Regional Analysis at the Peri-Urban Interface. *J. Clean. Prod.* 205, 76–85. doi:10.1016/j.jclepro.2018.08.323

Ma, W., Jiang, G., Li, W., Zhou, T., and Zhang, R. (2019). Multifunctionality Assessment of the Land Use System in Rural Residential Areas: Confronting Land Use Supply with Rural Sustainability Demand. *J. Environ. Manage.* 231, 73–85. doi:10.1016/j.jenvman.2018.09.053

Ma, W., Jiang, G., Zhang, R., Li, Y., and Jiang, X. (2018b). Achieving Rural Spatial Restructuring in China: a Suitable Framework to Understand How Structural Transitions in Rural Residential Land Differ across Peri-Urban Interface? *Land Use Policy* 75, 583–593. doi:10.1016/j.landusepol.2018.04.024

Manaugh, K., and Kreider, T. (2013). What Is Mixed Use? Presenting an Interaction Method for Measuring Land Use Mix. *Jtlu* 6, 63–72. doi:10.5198/jtlu.v6i1.291

Marshall, A. (1892). *Elements of Economics of Industry*. New York: Macmillan Pubishing Co.

Miguel, A., Trigalet, S., and Van, W. (2015). Effect of Land Abandonment on Soil Organic Carbon Fractions along a Mediterranean Precipitation Gradient. *Geoderma* 249-250, 69–78.

Motieyan, H., and Azmoodeh, M. (2021). Mixed-use Distribution index: A Novel Bilevel Measure to Address Urban Land-Use Mix Pattern (A Case Study in Tehran, Iran). *Land Use Policy* 109, 105724. doi:10.1016/j.landusepol.2021.105724

Munroe, D. K., van Berkel, D. B., Verburg, P. H., and Olson, J. L. (2013). Alternative Trajectories of Land Abandonment: Causes, Consequences and Research Challenges. *Curr. Opin. Environ. Sustainability* 5 (5), 471–476. doi:10.1016/j.cosust.2013.06.010

Musakwa, W., and Niekerk, A. V. (2013). Implications of Land Use Change for the Sustainability of Urban Areas: A Case Study of Stellenbosch, South Africa. *Cities* 32, 143–156. doi:10.1016/j.cities.2013.01.004

Nabil, N., and Eldayem, G. (2015). Influence of Mixed Land-Use on Realizing the Social Capital. *HBRC J.* 11, 285–298.

Newman, G., Park, Y., Bowman, A. O. M., and Lee, R. J. (2018). Vacant Urban Areas: Causes and Interconnected Factors. *Cities* 72 (72), 421–429. doi:10.1016/j.cities.2017.10.005

Niemira, M. P. (2007). The Concept and Drivers of Mixed-Use Development. *Icsc Res. Rev.* 14 (1), 53–56. doi:10.1016/j.hbrcj.2014.03.009

Pan, Y., Zeng, W., Guan, Q., Yao, Y., Liang, X., Zhai, Y., et al. (2021). Variability in and Mixtures Among Residential Vacancies at Granular Levels: Evidence from Municipal Water Consumption Data. *Comput. Environ. Urban Syst.* 90, 101702. doi:10.1016/j.compenvurbsys.2021.101702

Pašakarnis, G., and Maliene, V. (2010). Towards Sustainable Rural Development in Central and Eastern Europe: Applying Land Consolidation. *Land Use Pol.* 27, 545–549.

Queiroz, C., Beilin, R., Folke, C., and Lindborg, R. (2014). Farmland Abandonment: Threat or Opportunity for Biodiversity Conservation? A Global Review. *Front. Ecol. Environ.* 12 (5), 288–296. doi:10.1890/120348

Raj Khanal, N., and Watanabe, T. (2006). Abandonment of Agricultural Land and its Consequences. *Mountain Res. Develop.* 26 (1), 32–40. doi:10.1659/0276-4741(2006)026[0032:aoalai]2.0.co;2

Raman, R., and Roy, U. K. (2019). Taxonomy of Urban Mixed Land Use Planning. *Land Use Policy* 88, 104102. doi:10.1016/j.landusepol.2019.104102

Raudenbush, S. W., and Bryk, A. S. (2002). *Hierarchical Linear Models: Applications and Data Analysis Methods.* 2nd ed. Thousand Oaks, CA: Sage Publications.

Robledano-Aymerich, F., Romero-Díaz, A., Belmonte-Serrato, F., Zapata-Pérez, V. M., Martínez-Hernández, C., and Martínez-López, V. (2014). Ecogeomorphological Consequences of Land Abandonment in Semiarid Mediterranean Areas: Integrated Assessment of Physical Evolution and Biodiversity. *Agric. Ecosyst. Environ.* 197, 222–242. doi:10.1016/j.agee.2014.08.006

Sahu, A. (2018). A Methodology to Modify Land Uses in a Transit Oriented Development Scenario. *J. Environ. Manage.* 213, 467–477. doi:10.1016/j.jenvman.2017.12.004

Satsangi, M. (2007). Land Tenure Change and Rural Housing in Scotland. *Scottish Geographical J.* 123, 33–47. doi:10.1080/00369220718737282

Sharpley, R., and Vass, A. (2006). Tourism, Farming and Diversification: an Attitudinal Study. *Tourism Manage.* 27, 1040–1052. doi:10.1016/j.tourman.2005.10.025

Shultz, S. D., and King, D. A. (2001). The Use of Census Data for Hedonic price Estimates of Open Space Amenities and Land Use. *J. Real Estate Financ. Econ.* 22, 239–252. doi:10.1023/a:1007895631071

Siciliano, G. (2012). Urbanization Strategies, Rural Development and Land Use Changes in China: a Multiple-Level Integrated Assessment. *Land Use Policy* 29, 165–178. doi:10.1016/j.landusepol.2011.06.003

Smart Growth Network (2006). *This Is Smart Growth*.

Sohn, D.-W. (2016). Do all Commercial Land Uses Deteriorate Neighborhood Safety?: Examining the Relationship between Commercial Land-Use Mix and Residential Burglary. *Habitat Int.* 55, 148–158. doi:10.1016/j.habitatint.2016.03.007

Sohn, D. W., Moudon, A. V., and Lee, J. (2012). The Economic Value of Walkable Neighborhoods. *Urban Des. Int.* 17, 115–128. doi:10.1057/udi.2012.1

Song, Y., and Knapp, G. (2004). Measuring the Effects of Mixed Land Use on Housing Values. *Reg. Sci. Reg. Econ.* 34, 662–680. doi:10.1016/j.regsciurbeco.2004.02.003

Song, Y., Merlin, L., and Rodriguez, D. (2013). Comparing Measures of Urban Land Use Mix. *Comput. Environ. Urban Syst.* 42 (7), 1–13. doi:10.1016/j.compenvurbsys.2013.08.001

Taleshi, M., and Bishehii, S. (2012). Residential and Industrial Compatibility by Mixed Land Use, Zoning and Urban Design Case Study Vardavard Near Tehran Metropolis. *OIDA Int. J. Sustain. Dev.* 3 (4), 51–58.

Thorpe, A. (2018). 'This Land Is Yours': Ownership and Agency in the Sharing City. *J. L. Soc.* 45, 99–115. doi:10.1111/jols.12081

Tian, L. (2015). Land Use Dynamics Driven by Rural Industrialization and Land Finance in the Peri-Urban Areas of China: "The Examples of Jiangyin and Shunde". *Land Use Policy* 45, 117–127. doi:10.1016/j.landusepol.2015.01.006

Tian, L., Liang, Y., and Zhang, B. (2017). Measuring Residential and Industrial Land Use Mix in the Peri-Urban Areas of China. *Land Use Policy* 69, 427–438. doi:10.1016/j.landusepol.2017.09.036

Wang, Y., and Li, G. (2011). Functional Transformation and Spatial Restructuring of Rural Settlements in Southern Jiangsu: A Case Study of Suzhou. *City Plann. Rev.* 35 (7), 54–60. (in Chinese).

Wang, Y., Liang, L., and Mei, Y. (2014). Study on the Temporal and Spatial Characteristics of Rural Industry Pollution. *J. Henan Univ.* 44 (4), 428–435. (in Chinese).

Wiechmann, T., and Pallagst, K. M. (2012). Urban Shrinkage in Germany and the USA: a Comparison of Transformation Patterns and Local Strategies. *Int. J. Urban Reg. Res.* 36, 261–280. doi:10.1111/j.1468-2427.2011.01095.x

William, S. (1964). Marketing and Social Structure in Rural China. *J. Asian Stud.* 24, 3–43.

Williams, K. (2005). Spatial Planning, Urban Form and Sustainable Transport: An Introduction. *Spat. Plann. Urban Form Sustain. Transp.*, 1–13.

Williams, K. (2010). Sustainable Cities: Research and Practice Challenges. *Int. J. Urban Sustain. Develop.* 1, 128–132. doi:10.1080/19463131003654863

Xu, F., Ho, H. C., Chi, G., and Wang, Z. (2019). Abandoned Rural Residential Land: Using Machine Learning Techniques to Identify Rural Residential Land Vulnerable to Be Abandoned in Mountainous Areas. *Habitat Int.* 84, 43–56. doi:10.1016/j.habitatint.2018.12.006

Yang, R., Liu, Y., Long, H., and Qiao, L. (2015). Spatio-temporal Characteristics of Rural Settlements and Land Use in the Bohai Rim of China. *J. Geogr. Sci.* 25 (5), 559–572. doi:10.1007/s11442-015-1187-6

Yoshida, T., and Tanaka, K. (2005). Land-use Diversity index: a New Means of Detecting Diversity at Landscape Level. *Landscape Ecol. Eng.* 1, 201–206. doi:10.1007/s11355-005-0022-0

Yuan, Y., Zhao, Z., Shi, X., Niu, S., Zhu, P., and Rong, L. (2017). Strategy of Rural Residential Land Consolidation Based on the oriental of the Dominate Function of Township. *J. Nat. Resour.* 32 (12), 2089–2099.

Zhang, B., Jiang, G., and Qu, Y. (2019). Trade-off of Productive and Dwelling Space of Rural Settlement in Developed Areas. *Trans. Chin. Soc. Agric. Eng.* 35 (13), 253–261. (in Chinese).

Zhang, Z., and Zhang, A. (2020). Rural Development Types of Counties in China and Historical Change. *Resour. Sci.* 42 (2), 207–216. (in Chinese). doi:10.18402/resci.2020.02.01

Zhao, M., You, L., and Chen, C. (2015). Smart Shrinkage of Rural Human Settlements and its Planning Strategies. *City Plann. Rev.* 39 (7), 9–24. (in Chinese).

Zhao, Y. (2013). The Enlightenment of City's Smart Contraction Strategy on Village Planning. *World Chin. Econ. Yearb. Urban Rural Construction* 14 (2), 38–44. (in Chinese).

Zhen, L., Cao, S., Wei, Y., Xie, G., Li, F., and Yang, L. (2009). Land Use Functions: Conceptual Framework and Application for China. *Resour. Sci.* 31 (4), 544–551.

Zhou, Y., Luo, Z., and Geng, L. (2016). Smart Contraction" Oriented Mountains Rural Settlements Concentration Planning: Longquan Town, Yichang City, Hubei Province. *Planners* 32 (6), 86–91. (in Chinese).

Zhu, X., Wu, Y., and Wen, J. (2017). Paradigm and Spatial Pattern Analysis of Island Settlements Based on Mixed-Use Development: A Case Study of Zhoushan Work-Live Community. *Geogr. Res.* 36 (8), 1543–1556. (in Chinese).

Zhuo, Y., Zheng, H., Wu, C., Xu, Z., Li, G., and Yu, Z. (2019). Compatibility Mix Degree index: A Novel Measure to Characterize Urban Land Use Mix Pattern. *Comput. Environ. Urban Syst.* 75, 49–60. doi:10.1016/j.compenvurbsys.2019.01.005

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.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article or claim that may be made by its manufacturer is not guaranteed or endorsed by the publisher.