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Traditional Village Protection and Disaster Damage Analysis Based on Real-scene 3D Data

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The protection of traditional villages is crucial for preserving rural memory, safeguarding rural ecology, expanding agricultural forms, and achieving rural revitalization. In this study, we primarily utilized real-scene 3D data, along with big data analysis, remote sensing interpretation, and other technical methods, to construct application models based on real-scene 3D data analysis. These models are used to analyze the natural resource baseline, construction land indicators, landscape monitoring, and height control of traditional villages. We quickly assessed the damage to traditional villages caused by the "23.7" extraordinary heavy rainfall and flood disaster. We comprehensively considered factors such as topography, geological disaster prevention, catchment area, and flood passage to identify the reasons for minimal damage to traditional villages. The findings suggest that planners should use watershed and catchment areas as units for integrated coordination, emphasizing and strengthening the functional positioning of traditional villages. Postdisaster reconstruction can draw on the advanced experiences of traditional villages in site selection, flood control, drainage, and housing construction.

1. Introduction

Traditional Chinese villages are scattered across vast landscapes, bearing historical information from various periods, regions, and ethnic groups. These villages encapsulate the splendid culture of the Chinese nation over five millennia. Protecting traditional villages is essential for preserving rural memory, safeguarding rural ecology, expanding agricultural forms, and achieving rural revitalization.[(1–3)] Mentougou district boasts the largest number of traditional villages in Beijing, with the most concentrated distribution and best-preserved overall appearance. The district is rich in tangible cultural resources, offering significant value for

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protection and development, and serves as a focal point of Beijing's rural nostalgia. In April 2022, Mentougou district was selected as one of the first national demonstration zones for the concentrated contiguous protection and utilization of traditional villages, making it the first demonstration zone in Beijing.[4,5]

In the early stages, both domestic and international scholars focused on the ethnic characteristics, social customs, and rural planning of traditional villages. In recent years, research has primarily concentrated on the construction and spatial forms of traditional villages, their development and protection,[6] spatial distribution,[7,8] and rural tourism.[9] These studies are mainly based on various types of data, including natural, social, and economic data, utilizing methods such as statistical analysis and social network model-based analysis.[10–15] Despite the successful implementation of many traditional village protection projects over the years, numerous villages have been well-preserved and developed. However, challenges remain, including inadequate village landscape protection systems, high rates of village "hollowing out", insufficient infrastructure and public services, lack of industrial development momentum, and regional development imbalances. In particular, the severe rainfall and flooding on July 23rd severely affected Mentougou, Fangshan, and Changping districts in Beijing. Therefore, it is crucial to further utilize real-scene 3D data to analyze the damage to traditional villages and investigate the reasons behind it, ensuring that the research results are scientific and accurate.

In this study, we selected Mentougou district in Beijing as the experimental area, focusing on Jieshi and Weizishui villages. Using real-scene 3D data, which provides authentic, 3D, and temporal-spatial information reflecting and expressing production, living, and ecological spaces, we employed big data analysis and remote sensing interpretation methods. We deeply analyzed the historical changes, natural resource data, and current status of human-land-house data in the villages, aiming to uncover the prominent contradictions in the protection, renewal, and development of traditional villages. By integrating watershed data, we analyzed the impact of the extraordinary heavy rainfall on July 23rd on traditional villages and examined the reasons behind the damage. The findings provide effective support for the protection and development of traditional villages and the site selection for the reconstruction of ordinary villages.

2. Technical Route Construction

On the basis of the analysis of domestic and international policy documents and references, we combined multiple methods such as real-scene 3D, drone aerial photography, household interviews, and field surveys in this study. Using big data analysis, geographic information analysis, and other technical methods, we examined the situation of real-scene 3D data in aspects such as village historical changes, natural resource endowments, and human-land-house data. We deeply explored the prominent contradictions in the protection, renewal, and development of traditional villages and proposed a solution that includes spatial resource coordination and data platform support. Furthermore, we explored innovative directions for reform in the field of natural resource planning. We also analyzed the damage caused by the extraordinary heavy rainfall on July 23rd to traditional villages and investigated the reasons behind it. This lays the foundation for the subsequent protection, repair, and utilization of traditional villages and provides technical support for postdisaster reconstruction site selection. For more details, see Fig. 1.

3. Analysis of Village Patterns in Mentougou

Mentougou District is home to three Chinese historical and cultural villages, accounting for 60% of such villages in Beijing; 12 Chinese traditional villages, making up 46% of the city's total; 14 Beijing traditional villages, representing 31% of the city's total; and more than 50 villages with traditional features. Together, these villages form a unique cluster of traditional villages in western Beijing, making them significant samples for research. Among these, Weizishui and Jieshi villages are relatively underdeveloped and face various issues, making them typical examples. Therefore, these two villages were chosen as research subjects.

Both Weizishui and Jieshi villages are listed in the Chinese traditional villages directory. Weizishui village was included in the first batch of the directory in 2012, becoming one of the first nine traditional villages in Beijing to be listed. Jieshi village was included in the third batch in 2014, along with Yanhecheng village in Mentougou and Beikou village in Miyun. Both villages are located in the northern part of the Taihang Mountains, in Yanchi Town of Mentougou District (see Fig. 2). These villages are built along the mountains, forming unique settlements with distinct characteristics of ancient mountain villages in western Beijing.

3.1 Pattern and evolution of Weizishui village

Weizishui village is built along an east–west-oriented mountain valley, surrounded by mountains on all sides with lush vegetation, where forested areas cover about 88%. The natural ecological environment within and around the village is well preserved, maintaining the traditional village layout of "Nine Dragons Playing with the Golden Basin" and "Eight Waters Converging at Twelve Bridges" (see Fig. 3). Most villagers live around Nanyan road, which

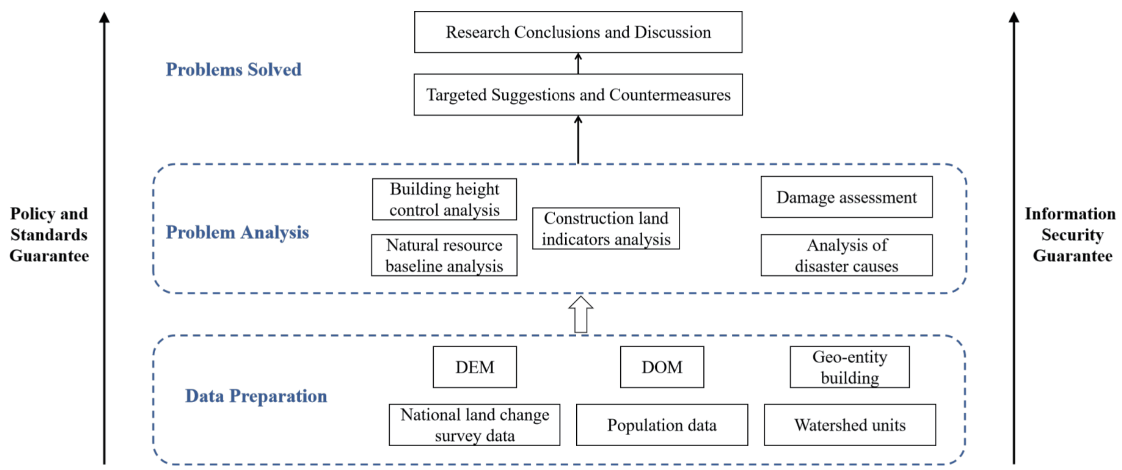

Fig. 1. (Color online) Technical route diagram.

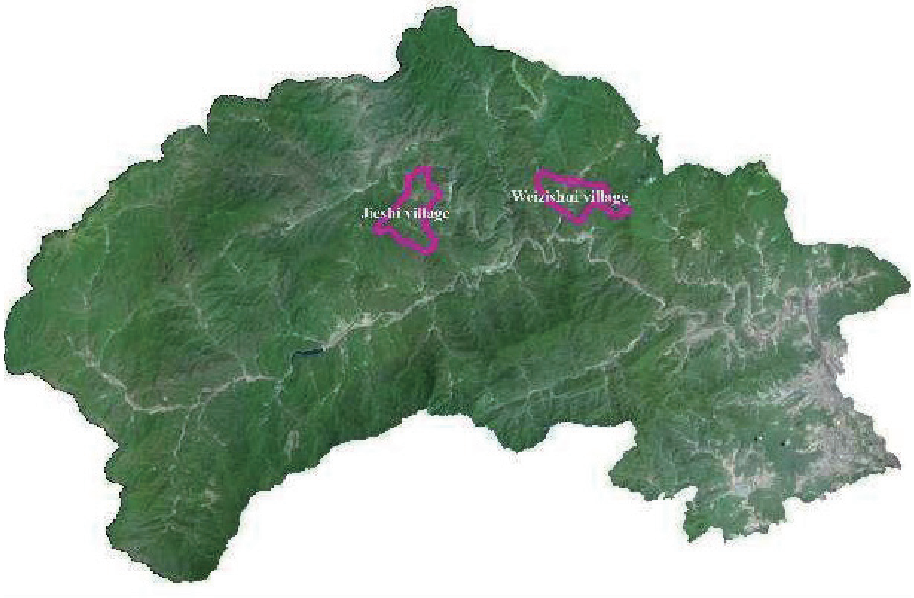

Fig. 2. (Color online) Area map of Weizishui and Jieshi villages.

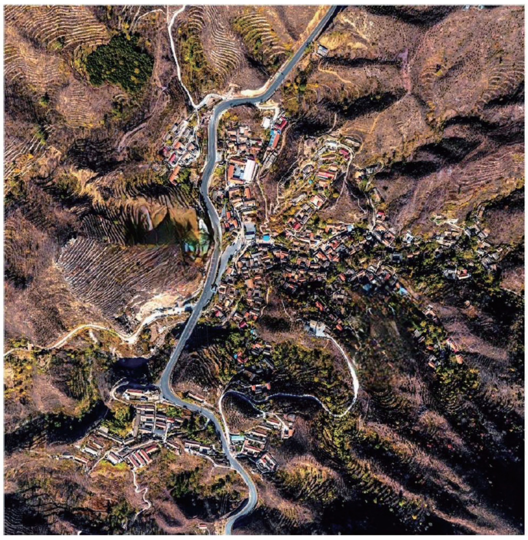

Fig. 3. (Color online) Layout diagram of Weizishui village.

traverses the village from north to south. Between 2001 and 2020, several houses were built near Nanyan Road.

Since 2001, the village has begun expanding its roads, completing a road connecting to the neighboring village by 2015. Around 2020, large-scale agricultural cultivation developed near this road, along with the construction of a branch road connecting to Nanyan Road (see Figs. 4 and 5).

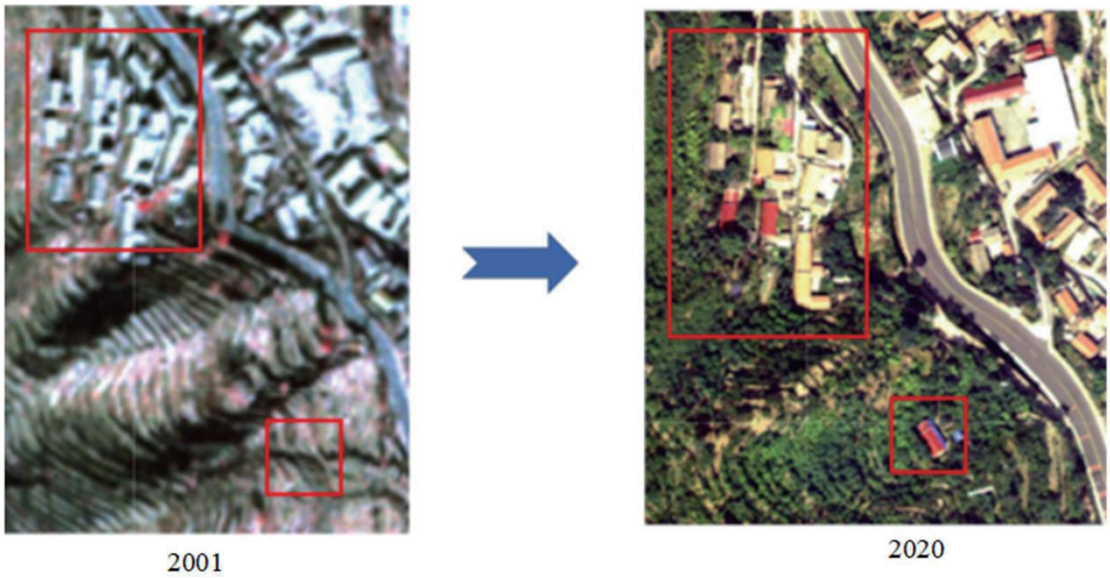

Fig. 4. (Color online) Partial map of new constructions near Nanyan Road.

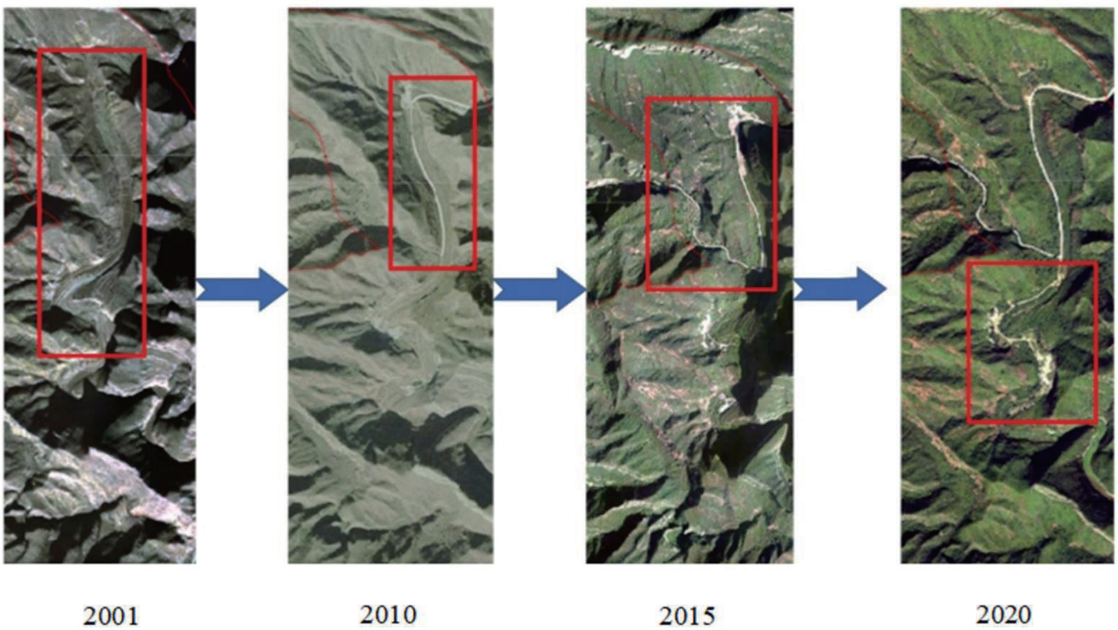

Fig. 5. (Color online) Annual road expansion diagram based on multi-period images of Weizishui village.

3.2 Pattern and evolution of Jieshi village

Jieshi village is surrounded by mountains on all sides and has undergone a process of returning farmland to forest, resulting in a forest coverage rate of more than 89%. The village is distributed in a narrow and elongated shape, divided into three branches, namely, East, West, and North, as shown in Fig. 6. The courtyards are built according to the terrain and topography, maintaining a coherent overall spatial system and preserving the characteristics of a mountain village.

Since 2001, the village has started to expand its construction, with the number of rural homesteads increasing annually in the southwest direction, as shown in Fig. 7. Starting from 2010, multiple rural roads have been constructed annually along Qingyang Road to facilitate agricultural activities and strengthen rural infrastructure, as detailed in Fig. 8.

4. Data Analysis

4.1 Traditional village protection analysis

4.1.1 Natural resource baseline analysis

Using the results of the second land survey (2009) and the 2022 national land change survey data (first draft submitted to the ministry), we analyzed the current land use situation of

Fig. 6. (Color online) "Three-branch" characteristic layout of Jieshi village.

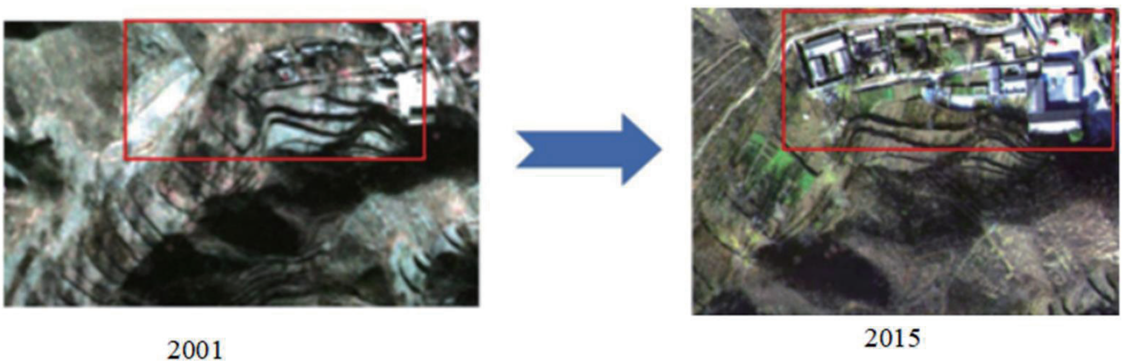

Fig. 7. (Color online) Partial map of new constructions.

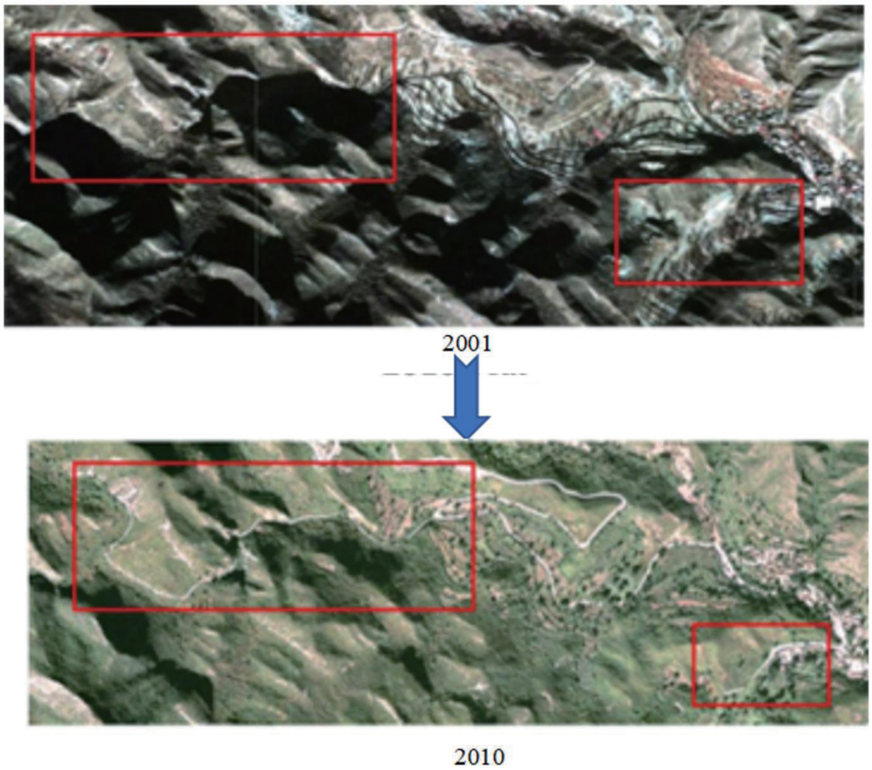

Fig. 8. (Color online) Partial map of new road constructions.

Weizishui village, as shown in Fig. 9 and Table 1. The proportion of construction land in both villages is relatively small (less than 2% of the total village area). From 2009 to 2022, the construction land area in Weizishui village remained basically unchanged, whereas Jieshi village saw a significant increase in construction land area due to development needs.

From the perspective of construction land area, Weizishui village's construction land area increased by 1.48 hectares, an increase of 9.79%, while Jieshi village's current construction land area increased by 4.61 hectares, an increase of 138.44%. The analysis of the conversion between construction land and nonconstruction land showed that, from 2009 to 2022, the main flow of land conversion in both villages was the construction of roads. In Weizishui village, about 5.62 hectares of land were converted from nonconstruction land to construction land, mainly from shrubland, orchards, and other grasslands to road land (4.72 hectares, accounting for 84% of the increase) and rural homesteads (0.53 hectares, accounting for 9% of the increase). About 4.14 hectares of construction land were converted back to nonconstruction land, mainly from rural homesteads and road land to shrubland (3.19 hectares, accounting for 77% of the increase), rural roads (0.46 hectares, accounting for 11% of the increase), and arbor forest land (0.17 hectares, accounting for 4% of the increase).

Overall, both Weizishui and Jieshi villages are remote deep mountain villages. Their overall construction development is relatively slow, with minor changes in land use proportion structure, and any increase in construction land area is driven by essential needs.

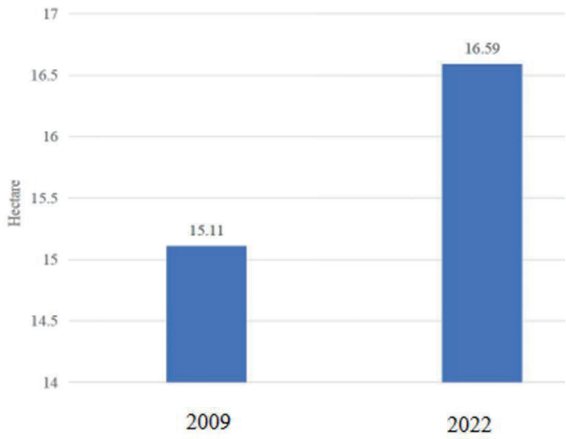

Fig. 9. (Color online) Changes in construction land use in Weizishui and Jieshi villages.

Table 1
Statistics of increased construction land areas in Weizishui and Jieshi villages.

Village	Construction Land				Nonconstruction land			
	Second land survey	2022 National land change survey			Second land survey	2022 National land change survey		
	Area (ha)	Area (ha)	Change area	Increase (%)	Area	Area	Change area	Increase (%)
Weizishui	15.11	16.59	1.48	9.79	866.94	865.46	−1.48	−0.17
Jieshi	3.33	7.94	4.61	138.44	684.99	680.38	−4.61	−0.67

4.1.2 Analysis of construction land indicators

On the basis of the 2022 national land change survey and data verified through topographic maps and imagery, combined with population data analysis, we determined the current land use status. The results of the detailed analysis are shown in Table 2. The data reveal that Weizishui and Jieshi villages commonly face issues such as high per capita land use, a large amount of idle land, gaps in public service facilities, are resource misallocation.

4.1.3 Building height control analysis

On the basis of MESH data and using 3D analysis techniques, we analyzed the building height control situation in traditional villages, as shown in Table 3. According to the "Mentougou district Rural Homestead and Housing Management Measures (Trial)", the eave height of one-story buildings should not exceed 3.5 m and the ridge height should not exceed 7 m. From the table, it can be seen that the overall building height control in Weizishui and Jieshi villages is satisfactory.

Table 2
Land use situation in Weizishui and Jieshi villages.

Village	Construction Land (ha)	Per capita village construction land (m^2)	Homestead land (ha)	Per capita homestead land (m^2)	Village idle courtyard land (ha)	Per capita idle courtyard land in villages (m^2)
Weizishui	8.27	590.71	7.42	529.67	2.15	153.57
Jieshi	3.83	766.00	3.56	711.11	0.99	198.00

Note:
1. In 2022, the per capita construction land for villages in Beijing was 331.29 square meters.
2. The population in per capita data is calculated on the basis of the permanent population of the village.

Table 3
Analysis of building heights in Weizishui and Jieshi villages.

Village	Number of buildings (unit)	Number of buildings on one floor (unit)	Number of buildings that comply with height control (unit)	Proportion of buildings that comply with height control measures (%)
Weizishui	812	808	651	80.57
Jieshi	267	267	226	84.64

4.2 Analysis of damage to traditional villages

Under the influence of Typhoon "Doksuri", Mentougou District in Beijing experienced an unprecedented extraordinary heavy rainfall on July 23, 2023. Using various methods such as big data analysis, remote sensing image interpretation, and on-site surveys, we conducted a comprehensive analysis on the impact of this heavy rainfall and flood disaster on ten traditional villages in the mountainous area of Mentougou.

4.2.1 Damage assessment

Using optical satellite imagery taken between August 2 and 5, 2023, we compared and interpreted pre- and postdisaster data for 296 administrative villages in Mentougou District. A total of 66 administrative villages experienced building damage. In the 10 traditional villages of Mentougou, a total of 159 individual buildings were damaged, with a disaster-affected building area of 6,771.11 square meters and an average damage degree of approximately 1.5%, as shown in Table 4. In contrast, the other 54 affected villages had 799 individual buildings damaged, with a disaster-affected building area of approximately 75,601.22 square meters and an average damage degree of approximately 2.9%, which is about twice the damage level of the traditional villages.

A detailed analysis of the damage to roads, bridges, buildings, and arable land, as well as the waterlogged areas within the traditional villages in Mentougou District, revealed significant findings (see Table 5). Among these, Yanhecheng village experienced the highest number of damaged buildings, roads, and bridges in terms of both location and area. Xihulin village had the most extensive damage to arable land, with approximately 353.61 acres affected across 34 locations.

Table 4
Comparison of disaster impact between traditional villages and general administrative villages.

Village	Disaster-affected area (m^2)	Total building area (10000 m^2)	Proportion of average degree of damage (%)
Traditional villages	6771.11	47.01	1.5
General administrative villages	75601.22	258.43	2.9

Table 5
Damage in Yanhecheng village.

Type	Number of damages (location)	Damage statistics
Road	256	69.17 ten thousand square meters
Bridge	6	401.85 meters
Building	141	0.68 ten thousand square meters
Arable land	130	952.29 acres
Waterlogged areas	33	54.76 ten thousand square meters

Jieshi village is located at the confluence of Linzitaigou and Yongding River basins. The total road damage area amounts to 8029.55 square meters; this includes three sections completely destroyed, covering an area of 1785.13 square meters, and 27 sections partially damaged, covering an area of 6244.42 square meters. In the southeastern part of the village, three buildings were completely destroyed, with a total area of 172 square meters. Weizishui village, situated in Xiama Ridge Valley, saw minimal damage to its houses.

4.2.2 Analysis of disaster causes

Using high-precision 3D DEM data, watershed data, gully area data,[16] flood models, and geological disaster data, we analyzed the causes of disasters in traditional villages.

Weizishui village, located within Tianzhuang Valley, is relatively less affected by floods compared with other villages in the same valley. The main flood discharge in Tianzhuang Valley is handled by Xiama Ridge Valley, which flows through the residential areas of Yubai, Gaotai, Songshu, and Tianzhuang villages. Large-scale floods and debris flows from upstream cause varying degrees of damage to homes, roads, and facilities in these villages. Weizishui village is situated far from Xiama Ridge Valley, at a higher elevation, with a small upstream watershed area. Additionally, rainfall in the catchment area did not trigger large-scale flash floods or debris flows. Consequently, the village was not affected by large-scale floods and debris flows from the upstream and surrounding areas of Xiama Ridge Valley. The flood discharge channel through the residential area serves as the main flood discharge passage in the catchment area, and it is unobstructed and aligned with the flood discharge direction, allowing floodwaters to pass quickly. The traditional village buildings have high foundations and were generally unaffected by the recent flood disaster (see Fig. 10 and Table 6).

In contrast, the floods flowing through the residential area of Jieshi village originate from both a large upstream catchment area and surrounding catchment areas (see Fig. 11). The large catchment area, combined with a debris flow at the eastern entrance of the village, directly led to the destruction of the district-level cultural relic, Longwang Temple.

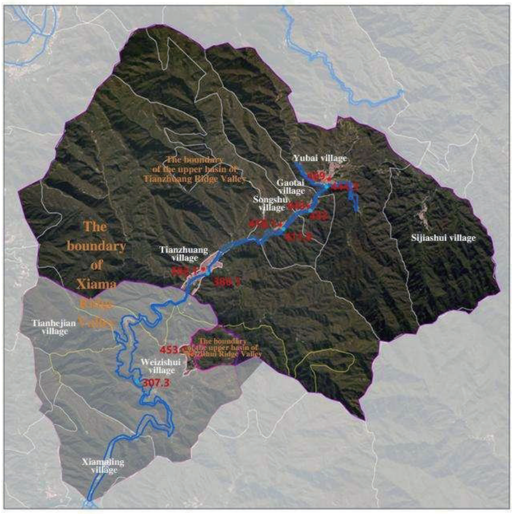

Fig. 10. (Color online) Analysis of damage causes in Weizishui village based on watershed and real-scene 3D data.

Table 6
Analysis of traditional villages in the Xiama Ridge Valley watershed based on real-scene 3D data

Elevation values of each village and Xiama Ridge Valley (m)				Distance from Xiama Ridge Valley (m)
Weizishui	453.1	Xiama Ridge Valley	307.3	923
Tianzhuang	392.1	Xiama Ridge Valley	386.1	21
Songshu	418.1	Xiama Ridge Valley	411.9	56
Gaotai	443	Xiama Ridge Valley	433	31
Yubai	469	Xiama Ridge Valley	444.3	43

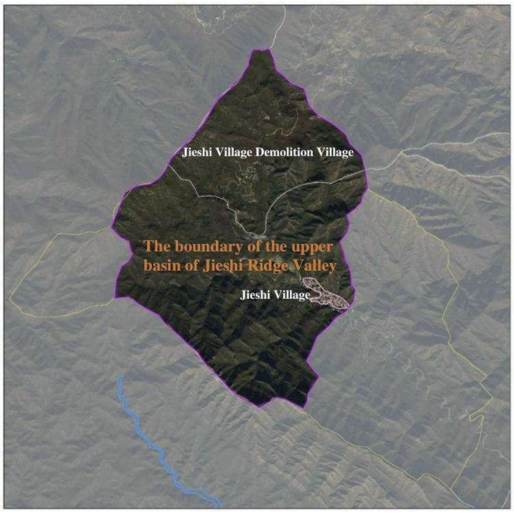

Fig. 11. (Color online) Analysis of damage causes in Jieshi village based on watershed and real-scene 3D data.

Comprehensive analysis revealed that traditional villages suffer less damage than ordinary villages. This is primarily because their construction fully considers the natural landscape and surrounding geological conditions, adapting to nature and local conditions. These villages have smaller catchment areas and stable surrounding rock and soil layers, ultimately forming a harmonious relationship between humans and nature. For instance, in house construction, site selection or high foundations are emphasized, with courtyards significantly elevated above adjacent roads to prevent rainwater from entering. The layout of streets and alleys aligns with the flood discharge direction, making the village space more resilient to disaster impacts during floods. From the perspective of integrated protection and systematic management of mountains, rivers, forests, farmland, lakes, grasslands, and deserts, planning should be based on watershed and valley units, highlighting and strengthening the functional positioning of traditional villages. In post-disaster reconstruction, relocated ordinary villages should fully consider terrain, geological disaster prevention, catchment area, and flood discharge channels. Specific measures can draw on the experiences of traditional villages in village site selection, flood prevention and drainage, and house construction.

5. Conclusions

In this study, we primarily utilized real-scene 3D data, integrating population, watershed data, gully area data, along with on-site surveys. Using big data analysis, remote sensing interpretation, and other technical methods, we developed an application model based on real-scene 3D data for analyzing the natural resource baseline, construction land indicators, landscape monitoring, and height control in traditional villages. Without entering the village, we used optical satellite imagery to quickly analyze the damage caused by the "23.7" extreme rainstorm and flood disaster on traditional villages, providing first-hand information for disaster assessment. Moreover, we conducted an in-depth analysis of the differences in damage between traditional and ordinary villages, providing reasons for these differences. The findings suggest that future planning should use watershed and valley units as the basis for comprehensive coordination, highlighting and strengthening the functional positioning of traditional villages. Postdisaster reconstruction should fully consider factors such as terrain, geological disaster prevention, catchment area, and flood discharge channels. Specific measures can draw on the experiences of traditional villages in site selection, flood prevention and drainage, and house construction. In the future, we will analyze the obtained data in combination with field survey data, precipitation, and more detailed watershed gullies.

Acknowledgments

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