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Unique traditional villages on the Loess Plateau of China: historic evolution and challenges to sustainable development of silo-caves

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Abstract

Silo-cave is a unique human habitation form on the Loess Plateau in northern China, which consists of an excavated 6–7 m deep pit as the courtyard and cave dwellings in the surrounding four walls. This architecture has had a history of more than 7000 years, and yet such “living fossils for the history of dwellings” are now facing great crises and challenges during rapid social and economic development. In this paper, remote sensing and GIS techniques are used to comprehensively and systematically investigate the spatial distributions and morphological characteristics of silo-caves at both the macro and micro scales. The research shows that silo-cave villages are mainly distributed in economically underdeveloped areas, such as West Henan (Yuxi), South Shanxi (Jinnan), Central Shaanxi (Guanzhong), and East Gansu (Longdong). The morphological evolution patterns of typical silo-cave villages are identified, including: (1) retaining the periphery and rebuilding the inner parts of the villages, (2) retaining the inner parts and expanding the periphery of the villages, and (3) rebuilding the inner parts and expanding the periphery of the villages. These patterns are demonstrated to be influenced by many factors, including landforms, traffic conditions, economic development, population growth, and administrative division adjustment. Sustainable development of these traditional silo-cave villages relies on administrative policy and planning, people’s awareness of cultural heritage protection, culture inheritance, industrial transformation, and public services.

Keywords: Traditional village, Silo-cave, Historic evolution, Sustainable development

Introduction

Traditional villages in China typically refer to those villages with long history, rich cultural and natural resources, and well-retained traditional lifestyle [1, 2]. They carry important signatures of human civilization over thousands of years in their historical archive and cultural landscapes [3]. What drew attention to this research is the traditional village of the silo-caves, a unique

dwelling form of human beings, located in the Loess Plateau of North China. It features a dwelling unit built by excavating the ground down to create a courtyard and then caving on the four walls of the courtyard (Fig. 1). Known as “the historic village below the horizon and living fossil for the history of dwellings” [4], it is the last surviving earth architecture constructed in accordance with the Rule of Subtraction, which is the opposition of the addition of material in building up architecture above ground, and thus it is considered a wonder of the human history of dwellings. The silo-cave, a representative of traditional villages with local characteristics, witnesses and preserves occurrence, development, and evolution of

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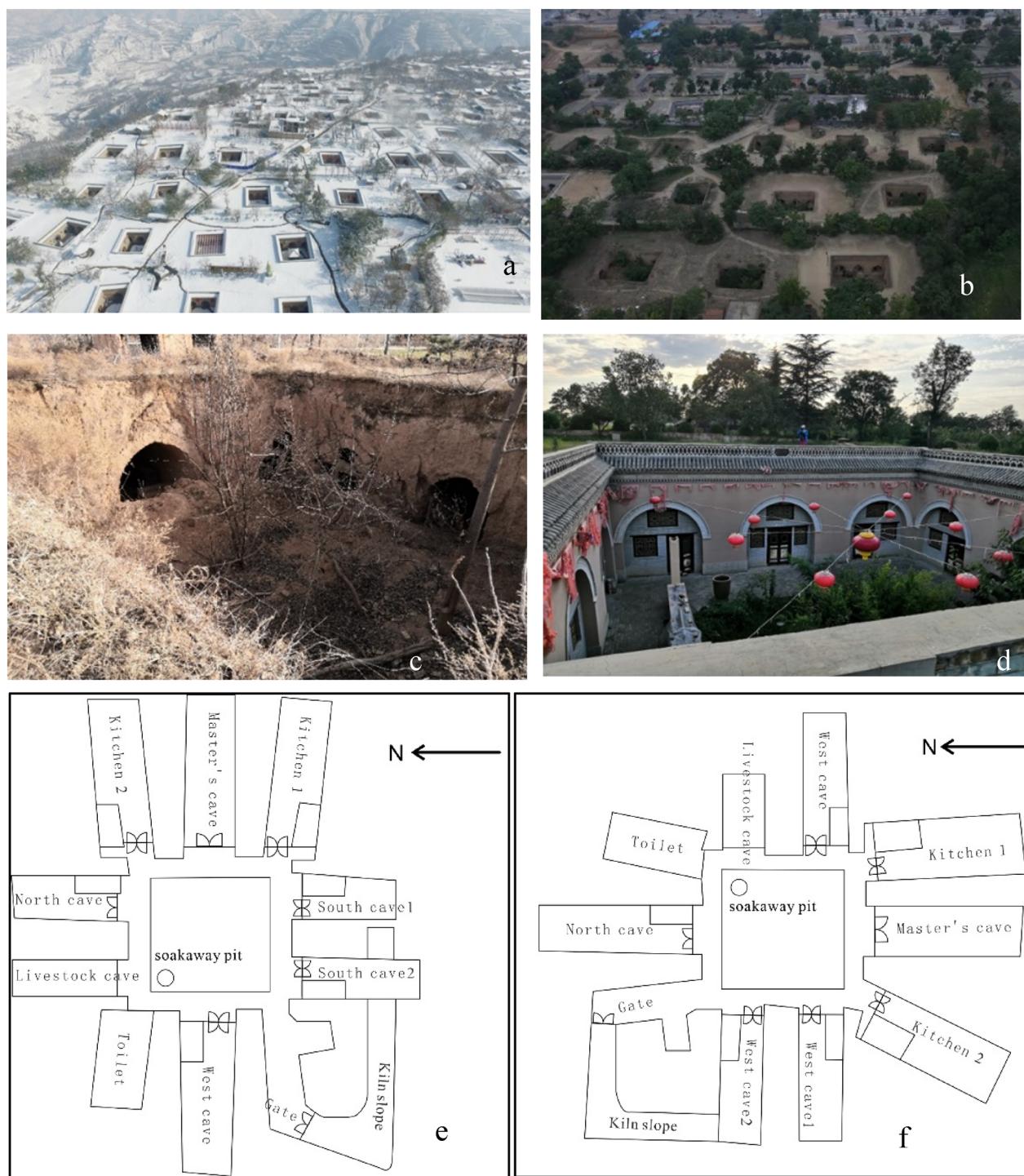


Fig. 1 The present traditional silo-cave villages: **a** the aerial view of Beiying Village, Zhangbian Town, Shanzhou District; **b** the aerial view of Qucun Village, Zhangbian Town, Shanzhou District; **c** the abandoned silo-cave of Zhangbian Village, Zhangbian Town, Shanzhou District; **d** the renovated silo-cave of Qucun Village, Zhangbian Town, Shanzhou District; **e** building plan of silo-cave (East); **f** building plan of silo-cave(South) (photos a & b by Mingyun Zhang; photos c & d by author; **e** & **f** Source from [81])

the agricultural civilization through thousands of years, and thus is considered highly valuable in history, architecture, sociology, geology, and art [5].

Similar to the valued historical architectures in other countries, silo-caves are confronted with various challenges during the process of modernization, globalization and urbanization, including commercialization, developmental destruction, and constructional destruction. Before the 1980s, silo-caves were basically the only housing type for the people living in the loess plateau area. There were a large number of traditional silo-cave villages with typical regional characteristics in this area. Over recent years, with improvement in the local living conditions, folks move from the underground to the ground. Numerous silo-caves have been abandoned and backfilled, or left for collapse. The total quantity rapidly reduces, and it becomes extremely difficult to appreciate the beauty and the values of such villages. The silo-caves traditional village is now facing the danger of loss of settlement features and vanishing of traditional culture.

It is crucial to emphasize the protection and development of traditional villages, which was probably first proposed by the French geographer Vidal Brands and his students in the 1920s [6, 7]. They used historical research methods to investigate the types, distribution, and evolution of rural settlements and their relationship with the agricultural system from the perspective of settlement science. As well, traditional villages have also been evaluated from perspectives of architecture, sociology, geography, archaeology, and history since the early 1990s, with a specific focus on their value characteristics [8–11], settlement patterns [12, 13], temporal and spatial evolution and formation mechanism [14–18], tourism development [19–23], and protection and utilization [24–27]. Much progress has been achieved in better understanding the spatial distribution, ecological environment characteristics, construction techniques, tourism value development, and protection laws and regulations of traditional villages.

The silo-cave, as a unique dwelling form, has also attracted increasing attention from academia. Studies have been carried out on its genetic mechanism, settlement form, construction technique, interior structure, landscape environment, as well as building protection and renovation. Meng et al. [28] analyzed the typical settlement forms of silo-caves in Dongzhi Tableland. Zheng et al. [29] investigated and classified the morphology of the traditional silo-caves in the Yuanshang area of Shanxi County, western Henan Province. Tang et al. [30] summarized the construction process of the silo-cave in the Sanmenxia area, the western Henan Province, and carried out building information modelling of silo-caves. Wang and Li [31] also studied the design and structure

of the silo-cave in western Henan, in terms of the construction technique and water drainage. Zhao [32] summarized the construction technology of silo-caves in the Pinglu County of Shanxi Province. Guo and Cheng [33] analyzed the factors affecting the changes of traditional silo-cave villages in Shanzhou District, Sanmenxia City, Henan Province. Ye and Zhao [34] discussed the status of landscape protection and utilization of the silo-cave village in Shanzhou City. Tian and Liu [35] investigated the protection and renovation design of the silo-cave village in western Henan. Li and Li [36] presented an effective method to develop traditional silo-cave village dwellings according to their own characteristics in the Beiyang Village, Shanzhou District, Sanmenxia City, Henan Province. Although these studies reviewed above have major contribution to the understanding of silo-caves villages and thoughts of their future, the areas they covered tend to be segmented and not systematic. To date, the authors cannot locate studies that examine this heritage from a macro and conjunctural research perspective [37]. Therefore, this research was considered a groundbreaking attempt to (1) document the evolving trajectories of silo-caves villages, (2) explain what socio-economic developments and cultural changes during the contemporary development in China interrelate to the rise and fall of the silo-caves villages, and (3) develop a theoretical framework to and database for silo-caves and its villages for further research and development.

Because of the rapid development of spatial information technology like remote sensing, GIS and digital measurement, the research of cultural heritages are gradually taking the advantages of these technologies to carry out heritages survey, spatial analysis, virtual restoration, visualization and other aspects. The spatial information technology has the macroscopic, quantitative, and visible features. They can acquire and analyze the spatial-temporal characteristics of surface features in a large space. This will help to identify the current distribution and spatial pattern of silo-caves.

In addition to the silo-caves' spatial pattern and changes in recent decades analyzed based on GIS, this paper specifically investigates the current distribution of silo-caves in middle reaches of Yellow River with Google Earth remote sensing images. The reasons and mechanisms for their temporal-spatial evolution are also discussed. The conclusion will include empirically based proposals that will help sustain and develop silo-caves villages.

Research methodology

Literature review in the previous section indicates that research on traditional villages in China, silo-cave villages included, generally focuses on the provincial

distribution, architecture feature, and tourism development of these traditional villages; however, macroscopic regional understanding of the overall framework of the spatial distribution of silo-cave is rarely reported, let alone its insights on its spatial evolution characteristics of typical traditional villages at different periods of time. This more systematic, marco and conjunctural research paper employed both quantitative and qualitative methods to investigate the temporal and spatial distribution and evolution of silo-caves with analysis of what socio-economic and cultural changes that have shaped their developments.

GIS spatial quantitative analysis methods

At present, quantitative analysis of the geographic characteristics of the spatial geometry and structure of silo-caves has not received sufficient attention. In fact, research on cultural heritage has begun to recognize the importance of the mixed research methods that inform both quantitative and qualitative analyses [38, 39], of which applications have produced promising research results. The rapid development and wide application of information technology over recent years such as digitalization, quantification, informatization, and visualization have evolved into the inevitable trends of research on heritage [40–47]. Thus, it would be a promising work to study the temporal and spatial distribution and evolution of silo-caves and the villages by using new technologies and methods such as remote sensing and GIS spatial analysis.

Remote sensing interpretation

With the help of the Google Earth images, we were able to investigate the present distribution of the silo-cave villages in the middle reaches of the Yellow River, evaluate the status of these silo-cave villages, and interpret the spatial distribution, morphological characteristic, utilization status, and quantity of these silo-cave villages. The spatial distribution of silo-cave villages in the middle reaches of the Yellow River was mapped, and remote sensing imaging of the utilization status of typical silo-cave villages was accomplished.

Furthermore, ArcGIS was used to analyze the vectorization of typical silo-caves and buildings on the ground, the data of which was collected from Google Earth's Multi-source and Multi-temporal Remote Sensing Images. Then, these images were linked to relevant dataset about silo-caves and their villages collected by our research team and other scholars. The synthesis of these data helped this research to analyze their nature and changes. Data for the base map of the database were the 1:50,000 standard topographic map. Moreover, data of the silo-cave and buildings of traditional villages on

the ground were collected mainly from the remote sensing imaging data since 1969 and the field investigation in areas of interest. The silo-caves and buildings above ground were matched according to the spatial coordinate and basic geographic data, and the spatial position of the settlement was corrected, in order to ensure accuracy and precision of data.

GIS spatial analysis

The spatial agglomeration characteristic of the settlement of silo-cave traditional villages was investigated via Kernel Density Estimation (KDE). This method is typically used to probe into the distribution characteristic of samples by characterizing the spatial variation of point density of samples across the study area, which can, in turn, identify and display agglomeration and dispersion of samples across the study area [48, 49]. This research measured the spatial agglomeration of settlements within a cross section at different time frames for typical silo-cave villages and presented a visual representation of the distribution patterns.

Historical-comparative and other qualitative analysis methods

Studies argue that historical comparative approach is to examine the generational and developmental process of the research object from the perspective of history. This approach can also objectively understand the development law and evolution track of the research object in different historical stages [50–52]. Furthermore, as the main stage of local life and an important carrier of local culture, the development and evolution of traditional villages is characterized by long-term and dynamic historical continuity [53]. Thus, this research employed historical-comparative approach was used to help collect historical data on silo-caves developments and analyze their changes. In this paper, we used this approach to compare the evolution tracks and dynamic mechanism of the spatial form of silo-cave traditional villages in different historical periods in order to accurately understand and comprehensively grasp the historical premise, evolution trajectories and policies at the time that shaped their developments in the villages. This is important to develop an accurate understanding of the existing forms of these villages and scientifically predict their future development trends. Therefore, the socio-economic and cultural data of the area were extensively collected. The following steps were carried out: (1) A comprehensive field investigation was carried out in the areas, which included Xizhangcun and Zhangbian Towns of the Shanzhou District, Sanmenxia City, Henan Province as well as Zhangdian Town of Pinglu County, Yuncheng City, Shanxi Province. The historic evolution, quantity change,

distribution of silo-caves, landscape characteristic, and challenges in the development of typical silo-cave villages were investigated and recorded. (2) The economic and demographic data of the sites were obtained from the government websites and relevant materials published in the literatures. Such data were derived from the relevant statistical bulletins and censuses in 1978, 2008 and 2018. (3) The research team obtained the history and evolution information of the traditional villages from the local chronicles and other historical data files related to the traditional villages. Documents and data were also collected from the archives bureaus in Shanzhou district and Pinglu county.

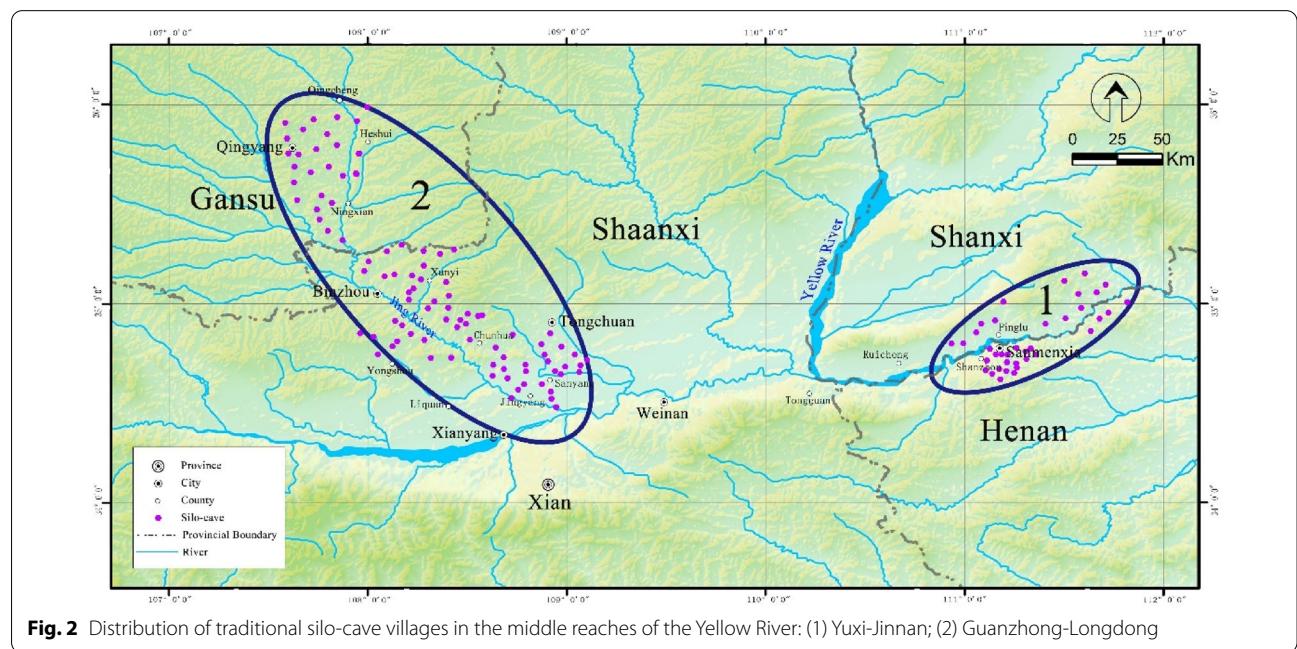
The historical and secondary data collected above help explore the main factors that affect the formation and development of the traditional silo-cave villages, reveal their internal organization and evolutionary developments, and search for a region-specific approach for culturally, ecologically, and point to potential economically sustainable development in the future. In turn, empirically-informed proposals will provide support and help to the protection, and sustainable development of this unique cultural heritage of humanity.

Results

Spatial distribution of the Silo-cave Villages

Remote sensing interpretation reveals that traditional silo-cave villages are mainly located in the terrace-like plain area of the Loess Plateau in North China, featuring thick soil layers and arid climate. The primary concentration of silo-cave villages is found in the Yuxi-Jinnan

(West Henan-South Shanxi) and Guanzhong-Longdong (Central Shaanxi-East Gansu) areas (Fig. 2). Silo-caves in the Yuxi-Jinnan area are mainly located at the central zones along mountains or the Yellow River, presenting the loess terrace-like plain landform. Specifically, the Yuxi silo-cave is mostly located at the loess terrace-like plain of the eastern margin of the Loess Plateau, such as Gongyi City, Xinan County, Shanzhou District, and Lingbao City [29, 31]. The Jinnan silo-caves are primarily built in the loess terrace-like plain area between the Zhongtiao Mountain and Yellow River, and the main concentration is seen in the towns of the mid-western Pinglu County (e.g. Zhangdian and Changle) [32, 44]. The silo-caves in the Guanzhong-Longdong area are concentrated at the loess terrace-like plain area of the valley of the Jinghe River. Moreover, the Guanzhong silo-caves are mainly distributed in the arid Weihei plain of the transition zone from the Weihe Basin to the Loess Plateau in the counties such as Changwu, Binzhou, Xunyi, Chunhua, Yongshou, Qianxian, Liquan, and Sanyuan of Xianyang City, Shaanxi Province [41]. Moreover, Longdong silo-caves accumulate at Dongzhi Tableland in the mid-eastern Qingyang, Gansu Province. From north to south these silo-caves concentrate at Qingcheng County, Heshui County, Qingyang City, and Ningxian County, where they spread outward from the central area of the county across the flat tableland surface. The main concentration is found in Qingyang City and its surrounding areas, followed by the areas along main roads. Areas near the river valley and gully are also seen with numerous silo-caves [28].



The areas with the concentrated distribution of traditional silo-cave villages are located in the central Loess Plateau and share distinctive regional and natural conditions, in terms of the landform, climate, soil, and so on. Meanwhile, these areas are all economically underdeveloped and classified as the traditional agricultural regions. The existence of these silo-caves and their villages are developed closely to its geographic locations and features; similar cultural practices are seen throughout these areas.

Characteristics of the landforms

The distribution areas of silo-caves are all located in the landforms of the loess tableland and terrace-like plain of the Loess Plateau, which are mainly characterized by a flat and wide top platform extending downward smoothly and slowly along the hill. The slope of the top platform is mostly of 1–3° and can reach 5° at the platform edge. The surrounding of the top platform is cut off by gullies. Due to such landforms featuring localized flatness, ancient residents living there had no cliffs and gully walls to build caves. Therefore, they innovatively constructed cave dwellings penetrating into the underground to create a relatively comfortable, wind-proof, and warm-keeping environment for living. This led to occurrences and development of silo-caves in these areas.

Characteristics of the climates

The Yuxi-Jinnan and Guanzhong-Longdong areas are both mid-altitude inland areas, and they are featured by the warm temperate continental monsoon climate. The four seasons are distinctive in these areas. Spring is dry and windy; summer is hot and rainy; the temperature drops rapidly in autumn; winter is cold and yet rarely snowy. Rainfall is concentrated in July–September, and the annual average temperature is 9–14 °C. To sum up, the climate there is characterized by hot summer and

cold winter, drought, limited rainfall, relatively strong wind with entrained sands, and intensive sunlight [54]. Due to such climate features, people living there try to use the dwelling design to offset the disadvantage of the natural conditions—the silo-cave architecture hides beneath the ground, with the overlying formation to facilitate the indoor environment warm in winter and cool in summer, the advantage of “cave dwelling”. The room temperature can maintain above 11 °C in winter and below 20 °C in summer. Furthermore, the small downward-excavated courtyard of the silo-cave can effectively block strong wind and therefore dust, and de-noise, to create an environment applicable to human dwelling and food storage. Clearly, silo-caves serve as a protective shield between humans and the harsh natural climate condition.

Characteristics of the soil conditions

These areas are endowed with abundance of loess. The loess deposit is thick, with a thickness generally of 20–250 m. Loess there are deposited during the early, middle, and late Pleistocene. The loess layer is rigid, tight, and commonly developed with vertical joints, therefore high capacity to maintain the standing posture and less prone to collapse [55]. It is resistant to vertical loading, earthquake, and alkaline corrosion. Moreover, the arid climate is in favor of the soils to keep dry and rigid, which improves the service life of cave-dwelling architecture. The natural conditions of areas with concentrated distributions of silo-caves are summarized in Table 1.

Homogeneous economic structure and development

The silo-cave concentration areas are all economically underdeveloped areas of middle and western China. In these areas, the underdeveloped economy suffers from an inferior economic foundation. The regional economy is mainly based on conventional agriculture, which leads

Table 1 Natural conditions of areas with concentrated distributions of silo-caves

Area	Landform	Elevation/m	Climate	Annual Average precipitation/mm	Annual Temperature/°C	Soil Thickness/m
Yuxi	Loess terrace-like plain at the eastern margin of the Loess Plateau	500–800	Warm temperature monsoon climate	550–680	13.6	20–70
Jinnan	Loess terrace-like plain between the Zhongtiao Mountain and Yellow River	500–700	Warm temperature monsoon climate	500–620	13.8	40–50
Guanzhong	Loess terrace-like plain of Guanzhong	400–600	Warm temperature monsoon climate	600–700	13.3	80–100
Longdong	Loess terrace-like plain of the Shan-Gan-Ning Basin (Dongzhiyuan)	1250–1400	Warm temperature monsoon climate	480–550	9.1	150–250

to a simple economic structure. Taking Shanzhou District in the Yuxi area, Pinglu County in Jinnan, Chunhua County in Guanzhong, and Qingcheng County in Longdong as examples, the per capita gross domestic production (GDP) and rural per capita disposable income in 1978, 2008, and 2018 are all below the national average levels (Table 2; Fig. 3). In the early stage, these areas are commonly seen with a lack of construction materials to build dwellings, and people living in such wide plains with insufficient natural barriers and construction materials have to seek shelter below ground. Therefore, the choice is made to excavate the ground and build homes, which gradually evolves into a dwelling habit during the prolonged history that continues up to now, and the villagers continue to struggle with their economy.

Evolution characteristics and changes of typical silo-cave villages

Historical evolution

The history of silo-caves dates back all the way to the early Neolithic Age. Ancient residents, living in the loess area and changing from nomadic to settlement, built their homes by caving the loess ground, which was highly

adaptive to the local condition [56, 57]. Such underground cave and semi-underground cave dwellings were found in the Peiliguang ancient cultural relic dating back to 9000–7000 years ago, specifically in both the Egoubei-gang relic of Xinmi [58] and the Tanghu relic of Tanghu, Henan [59]. Such dwellings are small in size, with areas generally below 10m² and depths below ground level of 0.5–1 m. Without doubt, these underground caves and semi-underground cave dwellings are the embryonic form of the later silo-caves, and further demonstrate the time-honored history and environment-adapted tradition of building homes in the loess area.

About 5000 years ago, the original form of cave dwellings started in the loess area in the late stage of the Yangshao culture. The oldest cave-dwelling architecture discovered so far is located in the Yanggu relic of the late Yangshao culture, Ning County, Gansu Province [60]. The subsequent Longshan culture (5000–4000 years ago) was seen with increasing cave-dwelling architecture, which gradually evolves into an important dwelling form for early human beings in the loess area. During this period, various styles of cave-dwelling architecture emerged, and the earliest silo-cave architecture came into

Table 2 Economic levels of areas of traditional silo-cave villages in 1978–2018

Term Area	Per capita GDP /RMB Yuan			Rural per capita disposable income /RMB Yuan		
	1978	2008	2018	1978	2008	2018
Shanzhou, Henan	324	18,484	45,855	126	4192	12,916
Pinglu, Shanxi	211	5986	18,164	101	2777	7776
Chunhua, Shaanxi	265	10,438	35,689	119	2946	9721
Qingcheng, Gansu	245	11,973	38,952	102	2696	8595
Nation-wide average	381	22,698	64,644	134	4761	14,617

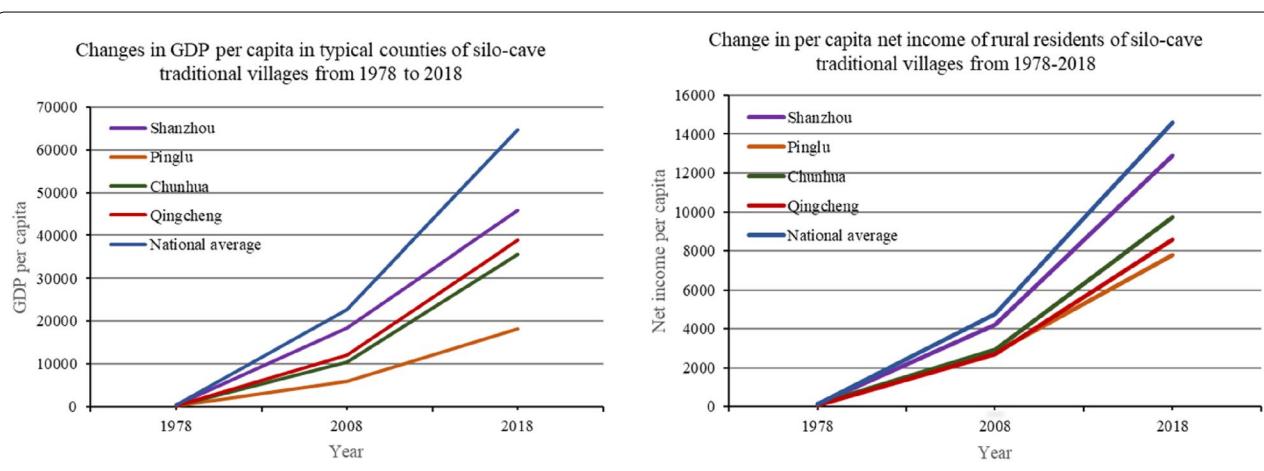


Fig. 3 Economic comparison of typical areas with traditional silo-cave villages

being—a cave dwelling with a vertically excavated vestibule. The cave dwelling itself is excavated on the wall of the vestibule. Such cave-dwelling remains were found in both the Taosi [61] and Dongxifeng [56] relics. Later in the Bronze Age (4000–3000 years ago), this form of cave-dwelling architecture became very popular in the loess area [62].

During the Qin and Han dynasties (2000 years ago), the masonry-timber structure gradually replaced the earth-timber structure and emerged as the main house form in China at that time. However, due to the traditional culture and economic limitation of the economy, cave dwellings remained an important dwelling form for residents in the loess area [63]. Cave-dwelling architecture that shared similarities in shapes and structures with the model silo-cave occurred during this period. A U-shaped tomb of the Han dynasty was found in Sanmenxia, and features multiple tomb caves distributed on the three sides of the tomb [64]. The overall tomb structure resembles a complete courtyard, and the look (from above) is extremely similar to the modern “silo-cave”.

From the late stage of ancient Chinese history to modern times, silo-caves became the most primary dwelling form in some areas of loess terrace-like plains. This phenomenon continued until the period of reform and opening up of China in the 1980s, after which residents in loess terrace-like plains gradually moved to the ground and lived in the buildings above ground, with the improved economy and change in the concept of dwelling. They were largely filled, collapsed, or abandoned in the mid-1980s to provide space for farmland, which results in a rapidly reduced quantity of silo-caves. The phenomenon was common in western Henan, southern Shanxi, Guanzhong, and Longdong areas where silo-caves were concentrated. Nonetheless, the government and the public have gradually been aware of the

uniqueness and scarcity of silo-caves since the 1990s, when policies on the development of rural revitalization, ecological civilization construction, and high-quality development strategies were implemented in the regions. More and more local governments and individuals start to protect or develop silo-caves into tourist places. For instance, several villages in the Shanzhou District have been included in the national or provincial traditional village list since 2012, including Miaoshang and Renmazhai Villages in the Xizhangcun Town as well as Beiyang, Qu, and Liusi Villages in the Zhangbian Town. Specifically, more than 80 silo-caves in the Beiyang Village have been renovated following unified planning standards, which becomes a silo-cave tourism site that displays the historical evolution of silo-caves as well as the lifestyle and folk skills of the people in the Yellow River basin to the world. This tourism site was granted with the Most Potential Scenic Spot Award in 2016, becoming one of the most successful cases in the tourism industry [36]. Similar successes have also been achieved in the Baishe Village of Sanyuan County and Lijiahougou Village of Qingcheng County in the Guanzhong-Longdong region [41]. These meaningful attempts and successes mark the entrance of the protection and utilization of silo-cave villages into a new stage (Fig. 4).

Morphological evolution patterns of typical villages

The loess plateau area in the southwest of Shanzhou District, Sanmenxia City is the largest and most concentrated area of existing silo-caves in China. According to the an estimate, there are still more than 100 underground traditional villages and nearly 10,000 silo-caves in this area [29]. By interpreting and analyzing remote sensing images of typical silo-cave villages in Shanzhou District since 1980, this paper managed to identify three patterns of morphological evolution

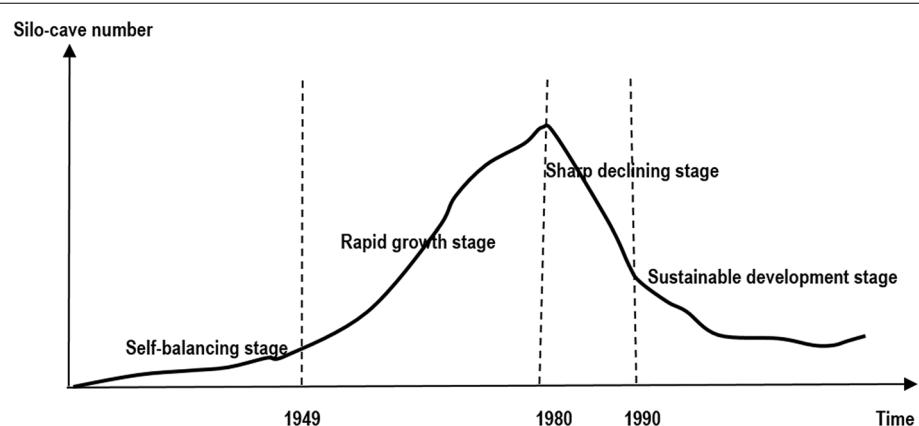
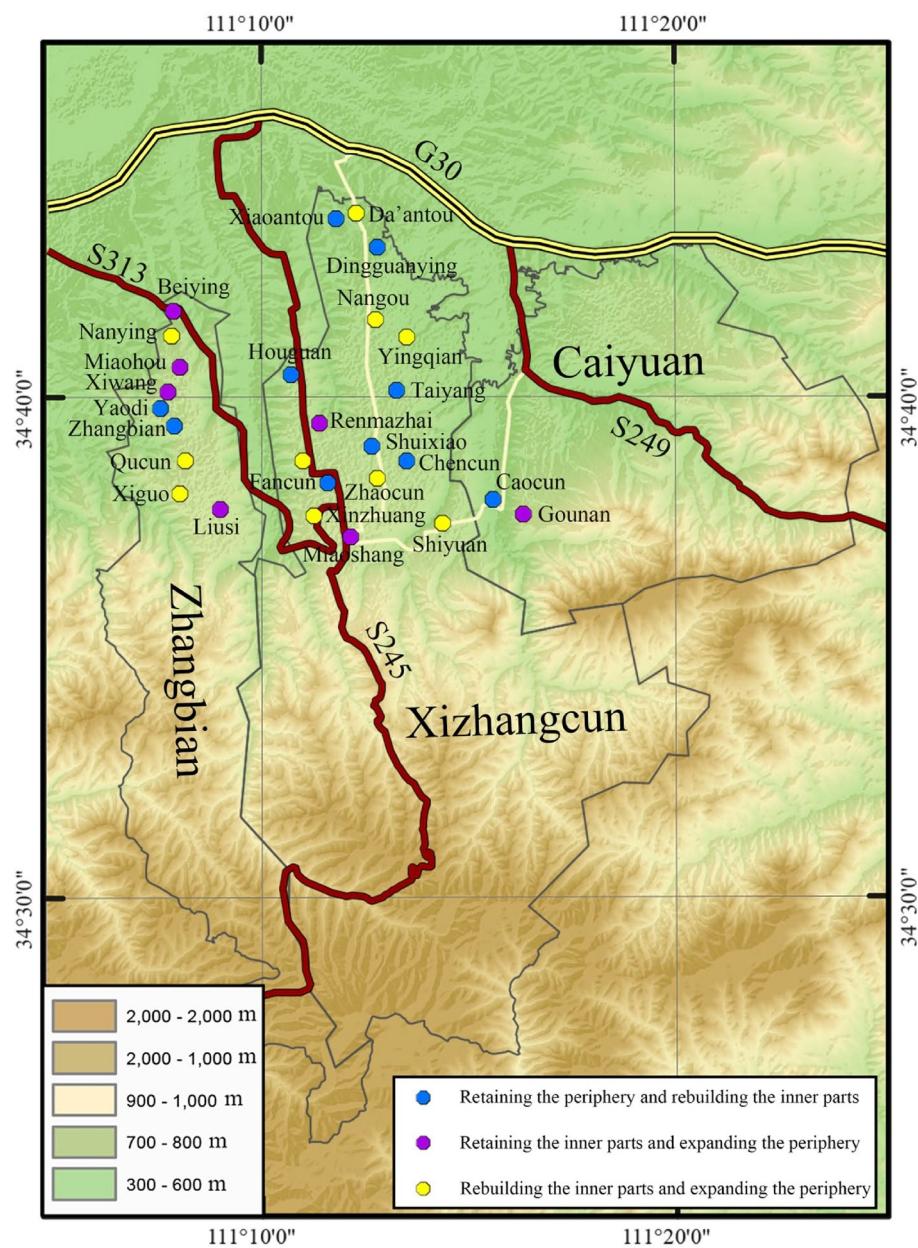


Fig. 4 Evolution stages of silo-caves

of traditional silo-cave villages, namely retaining the periphery and rebuilding the interior, retaining the interior and expanding the periphery, and expanding both the periphery and interior (Fig. 5). The following analyses are carried out on several typical silo-cave villages, including Houguan and Miaoshang Villages of Xizhangcun Town as well as Qucun Village of Zhangbian Town.

(1) Retaining the periphery and rebuilding the inner parts of the villages

The Dalei line of the provincial highway S245 leads directly into the center of Houguan Village is located in Xizhangcun Town, Shanzhou District. Before 1980, villagers mostly lived in silo-caves. Since 2000, dwellings above ground were built mainly along the provincial highway S245. By 2018, more buildings above ground have been placed inside the village along the main traffic roads with some traditional silo-cave architecture



retained along the periphery of the village (Fig. 6). The silo-cave settlement morphology shows that the periphery of the whole village remains unchanged for over three decades while the inner parts of the village were being rebuilt.

(2) Retaining the inner parts and expanding the periphery of the villages

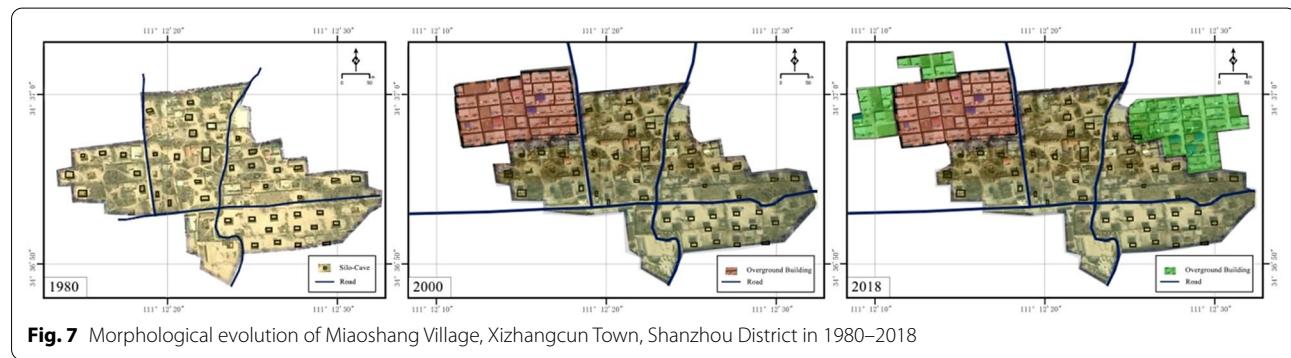
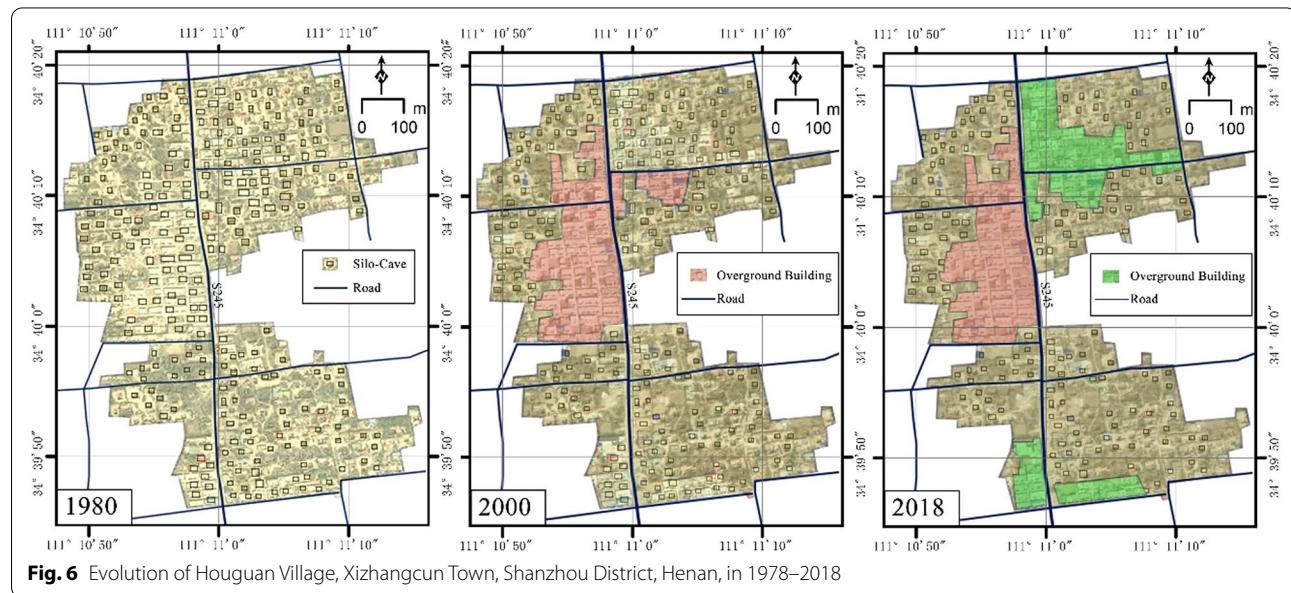
Miaoshang Village is located in Xizhangcun Town, Shanzhou District, Henan Province. The remote sensing imaging in 1980, 2000, and 2018 reveals a pattern of retaining the inner parts and expanding the periphery of the village. This change of the morphological evolution of the whole village (Fig. 7) means that the traditional silo-cave village is generally well preserved, and new buildings for the village are built as additions to the outside of the original village periphery with a well-planned manner.

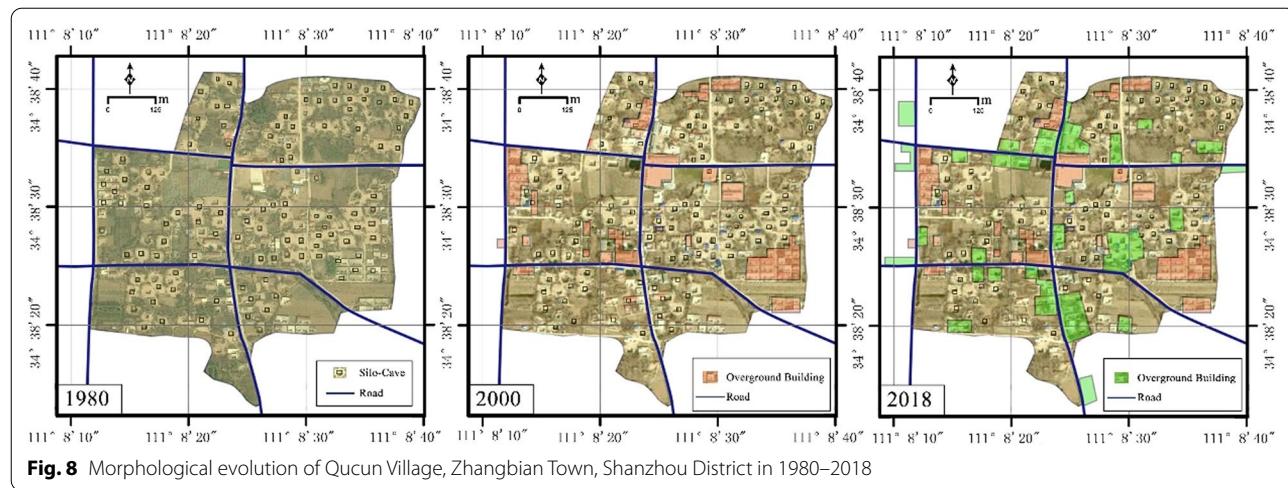
(3) Rebuilding the inner parts and expanding the periphery of the villages

Qucun Village is located in Zhangbian Town, also Shanzhou District, Henan. It is seen in the remote sensing imaging of 1980, 2000, and 2018 that the morphological evolution of the whole village is characterized by both rebuilding the inner parts and expanding the periphery of the village. Newly-built buildings above ground are randomly placed both in the inner parts and on the periphery of the original village (Fig. 8). In this evolution pattern, the traditional silo-cave village is generally found with simultaneous hollowing and periphery expansion, and the style and spatial texture of the previous traditional silo-cave village are compromised.

Evolution regularity of internal structures of typical traditional villages—taking Qucun village as an example

The analysis of the evolution of the village morphology in Qucun village finds that many buildings on the ground



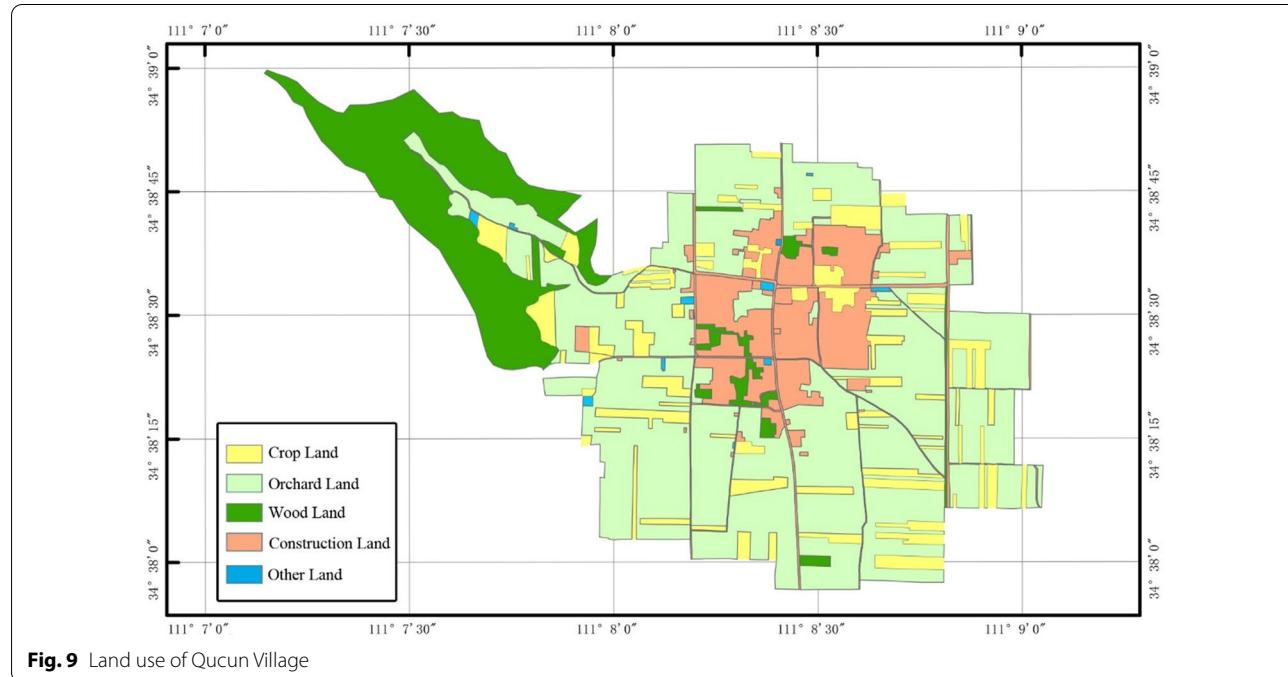


are laid out unreasonably. This negatively affects the style and texture of the village. Spatial information technology was used to extract information of silo-caves built at different time periods, including the newly built above ground. The data integrated from field investigations, the literature, and in-depth interviews local residents helped analyze the spatial form and structure of the Qucun Village. The analysis captures the natural, cultural, historical information, and evolution characteristics of the Qucun Village.

For example, our research showed that in 2018, the total village area of Qucun reached 287 hectares, among

which 40.75 hectares were of village construction; 152.67 hectares, of farming; 66.54 hectares, of woods; 27.04 hectares, of other usages (Fig. 9). There are now a total of 435 households for a total population of 1527 in Qucun.

Furthermore, remote sensing interpretation illustrates 172 silo-cave settlements across the village in 1969 (Fig. 10a). Over recent years, the quantity of silo-caves in Qucun gradually declines. According to the field survey and document reviewed, there were 130 silo-cave settlements in Qucun in 2018, presenting a reduction by 42 from 1969. The existing silo-caves were mostly built before 1949, among which two were built



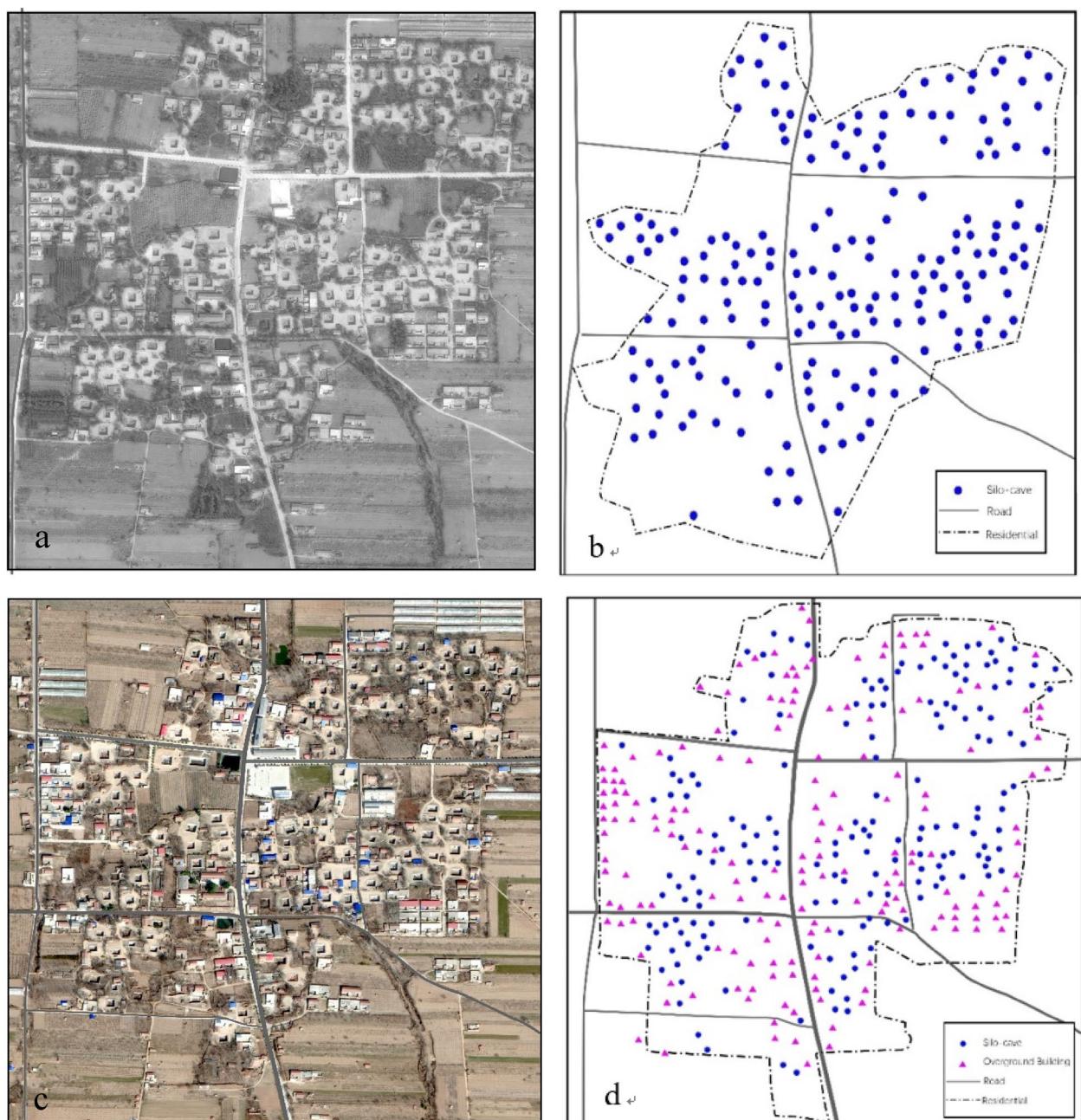


Fig. 10 Remote sensing imaging and vector graph of the settlement distribution in Qucun in 1969 and 2018: **a** Remote sensing imaging of Qucun, 1969; **b** Remote sensing interpretation of Qucun, 1969; **c** Remote sensing imaging of Qucun, 2018; **d** Remote sensing interpretation of Qucun, 2018

in the Ming dynasty; 32, in the Qing dynasty; 49, during the period of the Republic of China. Forty-seven silo-caves were built after 1949. Among the existing silo-caves, 74 (57% of the total) are well preserved, with structural integrity and retained style and features. Twenty-one silo-caves (16% of the total) are seen with slight inferior preservation, with partial structures

and decorative elements damaged. The rest of 35 silo-caves (27% of the total) are found with remaining overall structures and yet collapse of caves on one or more sides of the courtyard. Moreover, numerous above-ground dwellings have been built (Fig. 10c), including a total of 20 households with brick houses, mostly constructed before 2010, and 110 households with storied

and one-story houses, mostly built after 2010. The building distribution inside the traditional silo-cave village is vectorized via interpretation and digitization of the remote sensing image (Figs. 10b and d).

In addition, with the Density tool in the ToolBox of ArcGIS 10.1, the kernel density analysis (KDA) has been carried out on the settlements of Qucun in 1969 and 2018 (Fig. 11). The images reveal the agglomeration of traditional silo-caves in this traditional village in the following maps:

1. Fig. 11a indicates that there are mainly four agglomeration zones of silo-caves in Qucun, located in the northeastern, northern, central, and southwestern parts of the village, respectively.
2. Fig. 11b shows comparison of the silo-caves quality in 1969 and 2018. There was a huge quantity reduction, mostly occurring in the central and southern parts of the village. The existing silo-caves are concentrated in three zones, located in the northeastern, northern, and southwestern parts of the village.
3. Fig. 11c shows less-organized or rather scattered distribution of newly-built houses above ground. Such units are randomly placed inside the village. Yet some units are more concentrated in two zones which are in the northwestern and southeastern parts of the village.

Based on analysis of the morphological evolution characteristics and variation of settlement agglomeration of Qucun, a typical traditional silo-cave village, further functional division of this traditional village were carried out in our research, in accordance with the consistency of the overall village landscape spatial texture. The key protection zone for silo-caves is

demarcated, so as to provide planning reference for the local government's village governance in Qucun in the future. (Fig. 12).

Discussion

In this study, we used remote sensing and GIS technology to systematically investigate and analyze the spatial distribution and historical evolution of the traditional silo-cave villages. The temporal and spatial evolution of villages represents a highly regional human-land interaction process, and the status and characteristics that it presents are the inevitable result of the joint influence of economic, social, technological, cultural factors in the Loess Plateau. In this discussion, we attempt to analyze how these factors have affected the changes to the silo-caves and their villages as findings reported in the sections above.

Economic and social development challenges to the traditional silo-cave village

Since the reform and opening up in 1980s, the Loess Plateau, like other vast rural areas in China, has experienced rapid economic and social development, and the living standards of farmers have been continuously improved. The per capita disposable income of farmers in areas with the concentrated distribution of the traditional silo-cave villages, such as Shanzhou District, Henan Province, Pinglu County, Shanxi Province, Chunhua County, Shaanxi Province, and Qingcheng County, Gansu Province, has increased from 126 yuan, 101 yuan, 119 yuan, and 102 yuan per capita in 1978 to 12,916 yuan, 7776 yuan, 9721 yuan, and 8595 yuan per capita in 2018, which were 102 times, 77 times, 82 times and 84 times that of 1978 (Table 2). Farmers have the economic strength to improve their living conditions, and they have built

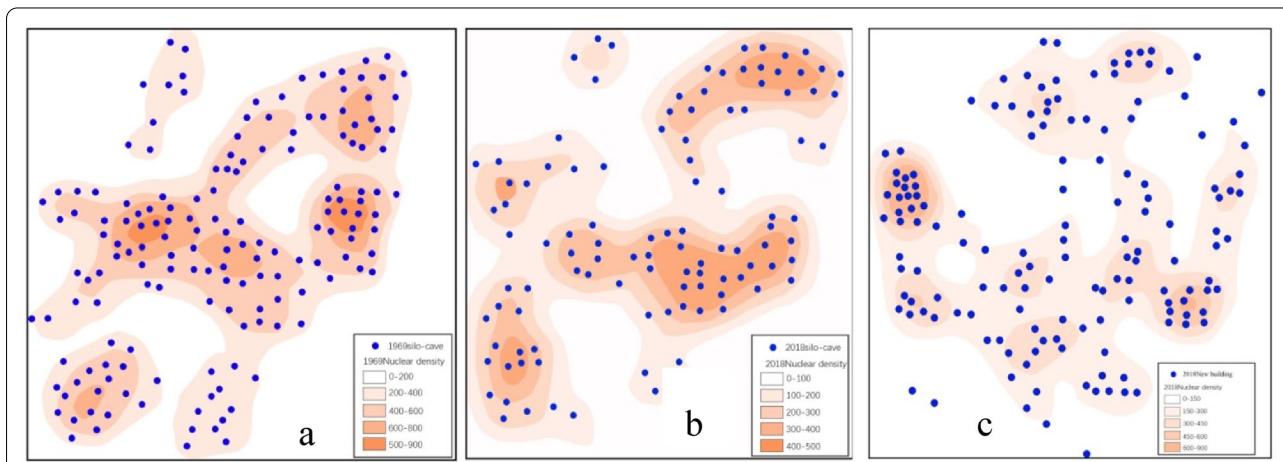
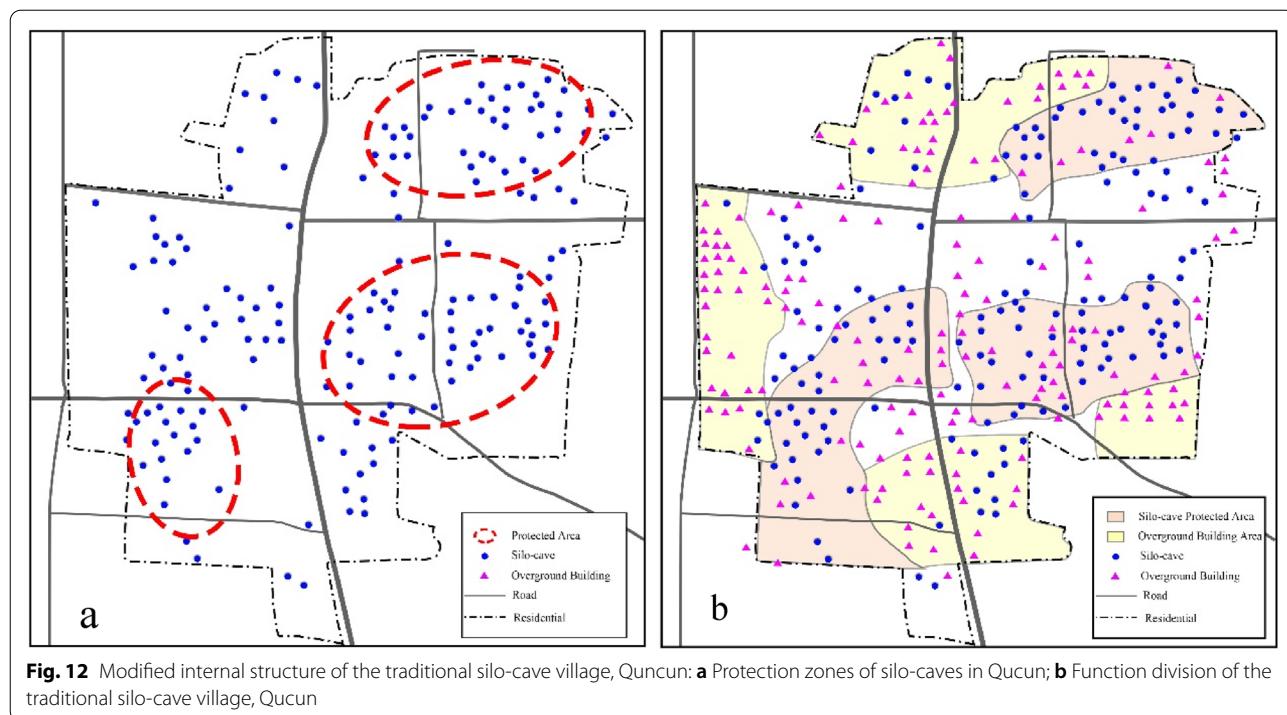


Fig. 11 Kernel density spatial distribution of silo-caves in Qucun: **a** Silo-caves in 1969; **b** silo-caves in 2018; **c** above-ground buildings in 2018



a large number of buildings above ground with brick-concrete structures in the original traditional silo-cave villages.

This phenomenon is widespread in traditional silo-cave villages in the Loess Plateau, and it shows the basic pattern of the higher the level of economic development, the lower the proportion of farmers choosing silo-caves. For example, the silo-caves in Luoyang, Gongyi and other western Henan regions where the economy is relatively developed in Henan have basically disappeared since 1980, and only part of the silo-caves have been retained in the more remote Shanzhou District, Sanmenxia City [65]. However, the number of silo-caves in Shanzhou District has decreased sharply. Take Qucun Village, a typical traditional silo-cave village we studied, as an example. In 1969, Qucun Village was basically dominated by silo-caves, and the proportion of silo-caves was more than 95%. In 2018, remote sensing images and field surveys showed that the proportion of silo-caves dropped to 50%. In addition, according to the Local Chronicles of Qingyang District, at the end of the 1940s, the silo-caves in Qingyang accounted for 87.8% of the total area of rural residential buildings. In the mid-1980s, silo-caves accounted for 47.34% of the residential building area in the district. After the 1990s, local residents built brick houses one after another, the original silo-caves were abandoned in large numbers, and many silo-caves collapsed because they were uninhabited [66]. Furthermore, according to data, in the early 1980s in Qiangjia Village,

Liangjiazhuang Village, and Deyi Village in Chunhua County, Shaanxi Province, the proportion of silo-caves were all over 80%. However, by around 2000, the proportion of silo-caves in the three administrative villages had dropped to 5, 25, and 50%, respectively [67].

The intensification of the rapid process of urbanization on the reduction of traditional silo-cave village

Since 1980s, large-scale and rapid urbanization process has put traditional villages under pressure from destruction or even extinction. Some scholars found that while the level of urbanization in China had increased from 17.9% in 1978 to 56.1% in 2015, the number of villages was declining at an average annual rate of nearly 3000 [68]. A large number of traditional villages are facing extinction, and with the acceleration of urbanization, the rate of disappearance of traditional villages is accelerating. In the Loess Plateau where Gansu, Shaanxi, Shanxi, and Henan Province are located, the impact of urbanization on the traditional silo-cave villages is even more severe. These areas are located inland, and the increase in urbanization rate is mainly due to the outflow of local surplus rural labor [69, 70]. With the acceleration of urbanization in these areas, a large number of surplus rural laborers have poured into cities and towns in batches, and many silo-caves have been abandoned. For example, there were more than 60,000 silo-caves in Shanzhou District of Henan Province in 2004. As more and more people,

especially young people, work outside the villages, the number of abandoned silo-caves is increasing at a rate of more than 3,500 per year [71]. The rapid urbanization process has further led to the survival dilemma of traditional villages.

Changes of dwelling preference as main factor for the decline of traditional villages

With the deepening of marketization, industrialization, and urbanization, the concept of modernization has penetrated into all aspects of rural areas. In the Loess Plateau, local residents have undergone profound and complex changes in the social psychology and values of the silo-caves that were shared for generations. Most people agree that living in silo-caves is a symbol of poverty and backwardness [72, 73]. In addition, the silo-cave itself has certain defects and shortcomings. For example, the lighting range of the silo-cave is small, and the indoor light is not good. The internal ventilation environment is single-sided, so the airflow cannot be circulated well. The ventilation and moisture-proof effect are poor [74]. Another disadvantage of living in silo-caves is about shuttling between their underground homes and daily necessities above ground. Let alone other types of everyday inconvenience, moving farm equipment from storage under the ground to ground level posts a challenge. The comprehensive index of living standards of residents is relatively low, and the villagers yearn for a more comfortable lifestyle. It has become a common phenomenon to abandon silo-caves to build and live in buildings above ground.

Reformed policies on farming and traditional villages as challenge to the massive reduction of silo-cave villages

As the population continues to grow, the cultivated land resources in the Loess Plateau are becoming more and more tense. In order to alleviate the increasingly intense contradiction between people and land, in the late 1980s, the regional government, where the silo-caves were concentrated, proposed that each household's new homestead should not exceed 0.4 mu. In addition, silo-caves (typically 1–1.5 mu in area) occupy 3–5 times larger areas than the current homestead, which was the main reason why local residents stopped building silo-caves in the late 1980s [75]. Beginning in the 1990s, local governments in these areas implemented the policy of 'reverting the silo-caves back to green fields'. A large number of silo-caves were reclaimed into cultivated land or other agricultural land, which results in the rapidly reduced quantity of silo-caves. For example, from 2002 to 2004, the Shanzhou District Government launched a policy of 'provide space for farmland' which aimed at re-purposing the abandoned silo-caves. While a net increase of 3,400

mu of cultivated land, silo-caves were largely filled and collapsed [76].

In summary, economic and social development, urbanization, and the improvement of residents' living standards are the main reasons for the reduction of traditional villages. Administrative policy and planning, self-agency of villagers, infrastructure construction, and adjustment of administrative division play a leading role in the evolution of the spatial morphology and structure of traditional silo-cave villages. Among them, administrative policy and planning and self-agency of villagers have become the most important two factors in the historical changes of the villages. As one of the main bodies of the protection and development of traditional villages, the government has played an increasingly important role in the revitalization of traditional villages. For example, Sim Loo Lee [77] conducted a survey of historic districts in Singapore and found that relevant government policies can promote the protective management of old shops. Frank Masele [78] found that private enterprise investment has brought challenges to cultural heritage protection and management of Tanzania, and he proposed that the cultural heritage protection plan should be implemented jointly by the local government and local communities. Our research on traditional silo-cave villages indicates that local governments play an important role in the development of silo-cave villages. Under the scientific planning guidance from the government and relevant management departments, and implementation of corresponding supporting policies, new buildings for the village are built in the periphery of the original village in a well-planned manner, and the traditional silo-cave village is generally well preserved. Government decision-making and planning guidance have become important official guiding factors for the sustainable development of such traditional villages. While the government provides policy, financial, and technical support for traditional villages, local residents play a decisive role in the protection and development of traditional villages. For example, Kirsty [79] conducted a study on tangible cultural heritage of Kuwait and found that local residents did not understand and value the heritage, which led to a mismatch between the values of the residents and their protection methods. Sarfo Mensah Paul [80] et al. conducted a study on Akyem Abuakwa in Ghana and believed that human factors such as farming and deforestation would threaten the protection of cultural heritage. For traditional silo-cave villages, more and more people, especially young people, are less willing to still live in the silo-caves, and many of them are abandoned, unused or collapsed. The "hollowing" and disorderly "spontaneous renewal" of traditional silo-cave villages are serious, and the overall texture of traditional villages has been

destroyed. Therefore, the willingness of local villagers to live and protect the silo-caves plays another decisive role in the protection and development of traditional villages. Although local residents' understanding of the value of the silo-caves has been improved in recent years due to governmental promotion and tourism development, it is still of crucial importance to enhance their initiative and spontaneity in using and protecting silo-caves.

Conclusions

The silo-cave building is a kind of building that is highly dependent on the geographical environment. The particularity of its building structure and materials determines the regularity of its spatial distribution pattern. The concentration areas of traditional silo-cave villages are all located in central Loess Plateau, sharing consistent natural conditions of landforms, soils, and climate. The landforms are all the loess tableland and terrace-like plain of the Loess Plateau. The top platform surface is flat and wide, with thick soil layers that are rigid, tight, and less prone to collapse due to the development of vertical joints and resultant capacity to maintain an erection. Loess is characterized by its resistance to vertical loading, earthquake, and alkaline corrosion. The climate is all warm temperature monsoon climate, with distinctive four seasons. The areas are dry with limited rainfall and relatively strong winds (with entrained sands). Moreover, these areas are economically underdeveloped and all classified as the conventional agricultural region. With such natural conditions, people choose to build homes by excavating the ground in place to live. This construction technique of homes can lower the living cost by using local materials and also achieve the purposes of keeping warm and protecting people from winds and entrained sands. Also, these areas share close geographical relationships and consistent cultural settings. The aforementioned factors lead to the occurrence, development, and inheritance of traditional silo-cave villages in the Yuxi, Jinnan, Guanzhong, and Longdong areas. Its emergence and development are closely related to the natural environment, social culture and life customs of the Yellow River Basin.

Incorporating traditional silo-cave villages into the context of environmental changes, traditional silo-cave villages in their historical change process of "formation-prosperity-decline" reflects the continuous adaptation and selection mechanism of people on the Loess Plateau to environmental changes. If we regard the traditional silo-cave village as the regional system of harmony between nature and human, resulting from the overall coordination among the human society and economy and the natural surroundings, the competing process of co-existing traditional silo-caves and

newly-built above-ground buildings inside traditional villages manifests evolution of the village morphology and structure. By investigating the evolution characteristics and patterns of the spatial morphology and structure of typical silo-cave villages, three evolution patterns for the morphology of traditional villages are identified, namely retaining the periphery and rebuilding the interior, retaining the interior and expanding the periphery, and expanding both the interior and periphery. Moreover, factors for different evolution patterns include the administrative policy and planning, self-agency of villagers, infrastructure construction, and adjustment of administrative division. The evolution of villages represents a highly regional human-land interaction process, and the status of evolution is the inevitable result of the specific current settings of society, economy, technology, and culture.

The traditional silo-cave village, known as the living fossil for the history of local-style dwellings, is facing severe crises and challenges in the current rapid development process of society and economy. It is a common problem faced by this type of traditional village that the number of silo-cave buildings has been rapidly reduced, and the destruction of traditional village style and texture has been exacerbating. In this study, remote sensing and GIS techniques are used to comprehensively and systematically investigate the spatial distributions and morphological characteristics of silo-caves. It has produced beneficial explorations on the influencing factors and evolution mechanisms of traditional villages. Moreover, beneficial explorations are implemented on the influencing factors and evolution mechanism of traditional villages, and it provides the foundation for digital protection and sustainable development of such traditional villages. Accordingly, the future work will integrate the influencing factors of silo-caves with their spatial shape, differentiated structures and sustainable development to establish an efficient system that can couple the influencing factors with sustainable, interactive development of silo-cave villages. More importantly, this study reveals that studying the tangible heritage without taking socio-economic and cultural changes across times would not be productive and meaningful. On this basis, a protection system with typical characteristics and protective element carriers will be built, which can help better provide the directions towards the sustainable development, protection, and inheritance of this type of traditional village.

In the process of sustainable development of traditional silo-cave villages in the future, the government and residents should form a good partnership. The government could search for development approaches and formats that are applicable to the local conditions on the basis of classifying the development models of traditional

silo-cave villages. Efforts shall be made to improve the guidance provided by government policy and planning, enhance protection and renovation of traditional architectures, facilitate mining and inheritance of regional culture, develop time- and environment-appropriate industry pattern design, properly allocate land resources, and optimize public services, in order to find a region-specific path for sustainable development of traditional silo-cave villages.

Appropriate technical measures should be taken by the local residents to improve the lighting conditions and ventilation effects so that they can meet people's requirements on living conditions. Moreover, efforts should be made to improve public services and integrate the public space to strengthen the sense of identity and belonging of local residents. Meanwhile, tourism should be promoted to provide industrial support and inject new vitality into the development of traditional villages. Therefore, a joint protection mechanism between the government and residents should be established to further clarify the protection subjects and protection responsibilities. The top-down policies should meet with the locals' needs. The villagers should have proper channels to voice their needs and aspirations. In short, we hope that the findings in this study will help contribute systematic and meaningful data to the larger database for silo-caves which is being developed. Scholars and policy makers from all over the world who are interested in silo-caves can collaborate to study and preserve this living heritage.

Abbreviations

GIS: Geographic information system; RS: Remote senses; KDA: Kernel density analysis; ha: Hectare (ha); GE: Google Earth.

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Authors' contributions

Data curation, LY; formal analysis, PL and RY; validation, XL and XW; visualization, PC; writing and editing LZ; review, RL and HHL. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

The data is available within the article.

Declarations

Competing Interest

All authors declare that they have no competing interest.

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