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The Impact Factors and Management Policy of Digital Village Development: A Case Study of Gansu Province, China

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Abstract: (1) Background: Along with the maturity of smart cities, digital villages and smart villages are receiving more attention than ever before as the key to promote sustainable rural development. The Chinese government has made great efforts in promoting the digital development of villages in recent years, as evidenced by policies intensively introduced by the central and local governments, making China a typical representative country in the world. (2) Methods: This paper evaluates the performance and geographic pattern of rural digital development by the Geographic Information System (GIS) in Gansu, a less developed province in western China, and analyzes the driving mechanism of rural digital development using GeoDetector, providing a basis for spatial zoning and differentiated policy design for the construction, planning and management of digital villages based on the GE matrix. (3) Results: First, the development of digital villages shows a prominent geographical imbalance, with 79 counties divided into leader, follower and straggler levels. Second, digital villages show unsynchronized development in different dimensions, with the village facilities digitalization index in the lead and the village economy digitalization index lagging behind. Thirdly, the development of digital villages is characterized by significant spatial correlation and spillover effects, with cold and hot counties distributed in clusters, forming a "center-periphery" structure. Fourth, the factors show significant influence differentiation. They are classified into all-purpose, multifunctional and single-functional factors by their scope of action, and into key, important and auxiliary factors by their intensity of action. Fifth, the interaction and driving mechanism between different factors is quite complex, dominated by nonlinear enhancement and bifactor enhancement, and the synergistic effect of factor pairs helps increase the influence by 1–4 times. (4) Conclusions: It is suggested that the government develop differentiated policies for zoning planning and management based on the level of digital development of villages in combination with the factor influence and its driving mechanism and promote regional linkage and common development and governance through top-level design.

Keywords: rural digitalization; smart village; influence factor; China

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1. Introduction

Since the concept of Smart Earth was introduced, the digital development of urban and rural areas has become a new global trend [1,2]. The concept of the Smart Village originated from the Smart City, and just as the Digital City is the fundamental condition for the construction of the Smart City, the Digital Village is the prerequisite for the construction of the Smart Village [3,4]. With the application and popularization of frontier technologies such as big data, cloud computing, artificial intelligence and Internet of Things, especially the maturation of digital cities and smart cities, traditional villages have gained an important opportunity for digital revolution and development, and the construction of digital villages and smart villages is becoming an emerging hot area [5,6]. The digital village is a novel form of modern village construction featuring digital and intelligent production elements with the Internet platform as an operation carrier, and emerging practical technologies such as Internet of Things, cloud computing and big data as the means [7]. To boost the development of rural digitalization, many countries and regions have increased their support in recent years, as evidenced by the "Rural Broadband ReConnect Program" proposed by the U.S. Department of Agriculture [8], the "Smart Countryside Initiative" proposed by the European Commission [9,10], the "Outline of Digital Rural Development Strategy" introduced by the Chinese central government [11] and Russian countryside online projects [12]. The level of rural digitalization varies greatly from country to country due to differences in start-up time, emphasis, investment intensity and driving mechanisms. Therefore, to better promote the construction of the Digital Village or Smart Village, it is of great theoretical significance and practical value to scientifically evaluate and analyze the characteristics of the current situation, determine the development disparities of different regions and reveal their influence factors and driving mechanisms [13].

China is one of the earliest countries to integrate digital technology into rural development, and the government regards digitalization as an important strategy to achieve rural revitalization and sustainable development and make its planning and construction of "digital villages" a typical representative in the world [14]. The Chinese government has long regarded information technology as an important means to promote the development of rural modernization, and as early as 2005 the central government proposed to strengthen the development of agricultural and rural information technology. China is currently in the stage of rapid urbanization, characterized by a massive migration of rural populations to cities and towns and increasingly serious rural shrinkage and decay. To promote rural revitalization, the Chinese central government proposed the "Digital Rural Development Strategy" in 2018. Based on top-level design, the central government of China has successively released national policies such as the *Outline of Digital Rural Development Strategy*, the *Plan for the Development of Digital Agriculture and Rural Areas* (2019–2025) and the *Notice on the Implementation of the National Digital Rural Pilot Project*. To push the all-round construction of digital villages, the central government has further selected 117 counties for pilot projects of digital villages. The pilot counties are in all provincial-level administrative regions (including provinces, autonomous regions and municipalities directly under the central government), including 27 counties removed from the list of national-level poverty-stricken counties. To better implement the central government's macro policies, about 70% of local governments have successively formulated digital village construction plans, practice solutions and other region-specific policies (according to the incomplete statistics by the authors based on policies released on provincial government websites as of 23 October 2022), and some provincial governments (e.g., Guangxi, Yunnan, etc.) have further set provincial digital village pilot counties (cities and districts). The results of the research on China can serve the Chinese government in policy making and can also provide constructive information for the development of digital villages or smart villages in similar countries around the world.

2. Literature Review

Digital villages and smart villages are the physical manifestations of rural information development at different stages with no essential difference. Therefore, this paper integrates the two in the literature analysis. Scholars are currently interested in the following areas.

2.1. Theoretical Research

Scholars have discussed the concept [15], analyzed the necessity and feasibility of rural digitization and intelligent development and proposed different approaches for different regions [16]. They also focus on thematic research on the development of different types of digital villages and smart villages. Most of the papers are dedicated to the analysis of the Smart Tourist Village [17], Taobao Village [18], such as the rural smart tourism service [19] and the development [20] model, which are spontaneous responses of villages to the development of smart tourism and e-commerce. Very few studies deal with the digital preservation and heritage strategies of smart eco-villages [21] and traditional ancient villages [22], such as the construction of traditional village digital archives [23], whose digital development is driven by government ecological or heritage conservation investments. Theoretical research is currently limited to superficial areas such as the definition of the basic connotation of digital villages and smart villages and the deconstruction of the development model of special types of digital and smart villages, while deep academic discussions on the driving mechanisms and evolutionary laws of rural digital development still remain blank (Table 1).

Table 1. Literature review and research gaps analysis.

Objectives	Methodologies	Literatures	Gaps
Concept and definition	Phenomenon observation and logical reasoning	Satola, Budziewicz-Guzlecka [15,16]	Driving mechanism and evolution law
Types and Development mode	Case study and qualitative analysis	Ciolac, Leong, Hu, Li, Huang, etc. [17–23]	
Digital or intelligent application modules		Ogryzek, Mounce, Dai, Francini, etc. [24–31]	Development demand and local supporting capacity
Latest applications of emerging digital and intelligent technologies		Irwansyah, Kaur, Ram, Cvar, etc. [32–38]	
Macro development strategies and policies	Policy analysis and pilot experience promotion	Stojanova, McGuire, etc. [39–41]	Quantitative analysis and evidence-based decision-making
Micro-spatial planning and design schemes analysis	Case study and qualitative analysis	Zavratnik, Wojcik, Bielska, etc. [42–45]	

2.2. Technical Research

Besides the analysis of digital or intelligent application modules, including development paths and solutions for smart rural transportation [24,25], smart land [26], smart grids [27], smart metering [28], smart finance [29], smart governance [30] and scalable architecture for smart villages [31], the scholars focus on the latest applications of emerging digital and intelligent technologies in the development of villages or hamlets [32], including blockchain [33], Internet of Things [34,35], machine learning [36], artificial intelligence [37] and big data technologies [38]. The increasing application of new generation information technology such as the Internet, big data and cloud computing in digital villages and new rural infrastructure in recent years has significantly accelerated digital, networked, intelligent and smart rural development and narrowed the digital divide between urban and rural areas. For example, the use of the Beidou System and artificial intelligence for the scientific management of crops improves management efficiency. Besides, QR code technology enables the full traceability of agricultural products from field to table; e-commerce and live streaming platforms increase the sales of agricultural products and expand the geographical scope of sales. Of note is that the current research is more based on the technology development trend, with less effort focused on the needs and development support capacity of digital village construction.

2.3. Policy and Planning Research

On the one hand, they analyze macro development strategies and policies, including Stojanova's analysis of the policy evolution of the EU Smart Village [39], and the introduction of rural smart policy in Australia and the 'smart' rural development program in Northern Ireland by Randell-Moon [40] and McGuire [41]. On the other hand, they conduct micro-spatial planning and design schemes analysis; for example, Zavratnik [42] analyzed the case of smart village initiatives and practices in Slovenia, Wojcik [43] and Bielska [44] assessed the spatial model and planning digitization of smart village development in

Poland and Li [45] analyzed the digital village spatial design schemes in Youzhaqiao Village, Guangshui, China. Notably, these practices are innovative, but unfortunately, they are based more on empirical and exploratory work and at odds with trends and requirements for quantitative analysis and evidence-based decision-making.

2.4. Research Gaps Analysis

In summary, a series of valuable papers are available on digital and smart village development, mostly focusing on the concepts, types, functional modules and technological applications, development policies and spatial planning of smart and digital villages [46]. All the conclusions provide a valuable reference for this study. However, there are some limitations in existing studies. First, there is still insufficient scholarly research on how to evaluate the level of digital and intelligent development of villages and measure interregional differences and correlations though it is a key basis for government management. Although Venkatesh [47], Gerli [48], Erdiaw-Kwasie [49], Chen [50] and Labrianidis [51] analyzed the digital divide in Indian, British, Australian, Chinese and European villages, they failed to give satisfactory answers to the questions above (on the degree of development and its spatial effects). As Maja [52] stated, despite the good results of digital and smart village research and practice, research on indicators and criteria that can be used to evaluate them is still deficient as of now. Second, the construction of digital and smart villages is influenced by many factors, and there are no papers specifically analyzing the driving factors and their mechanisms of action. As with digital and smart cities, revealing the deep-seated driving mechanisms of digital and smart development in rural areas is a prerequisite for the proactive government intervention and management of digital and smart village construction and also a basis for setting development goals, policies and plans in different regions according to local conditions [53]. Therefore, it is very necessary to study the influence factors and their mechanisms for the theoretical construction and practice of digital and smart villages.

3. Materials and Methods

3.1. Study Area: Gansu Province

Gansu Province is in northwestern China and is a less developed region (Figure 1). The study area covers 79 county-level administrative districts in Gansu Province, excluding Chengguan, Qilihe, Xigu and Anning districts in Lanzhou City, Jiayuguan City (which has no subordinate districts or counties), Jinchuan District in Jinchang City, Baiyin District in Baiyin City and Subei County in Jiuquan City (Figure 2). Eight units are excluded from the study area because of the data deficiencies. In the *Index of Digital Rural Counties, 2020*, data are only available for counties where the ratio of agricultural value added to GDP was less than 3% in 2019, excluding data for prefecture-level cities.

We chose Gansu as the study area mainly for the reasons of policy support and development status. Policy support comes from both central government and local government. According to the *Notice on Announcing the List of National Digital Rural Pilot Areas*, Gaolan County of Lanzhou City, Yumen City of Jiuquan City and Gaotai County of Zhangye City are in the first batch of national pilot areas for digital villages. Driven by the national pilot and supported by the central government, Gansu has carried out provincial pilot construction in 5 cities, 10 counties, 50 towns and 500 villages. In the *Outline of the Fourteenth Five-Year Plan for National Economic and Social Development of Gansu Province and the Visionary Goals for 2035*, the provincial government clearly put forward “the digital rural development strategy”. The city and county governments also attach great importance to the construction of digital villages. For example, Gaotai, a national pilot county, has released the *Development Plan of Digital Villages in Gaotai County (2020–2024)* and the *Implementation Plan of the National Pilot Construction of Digital Villages in Gaotai County*. With the support of government investment, Gansu has witnessed faster construction of digital villages than its counterparts, quite typical across the country. According to the *County Digital Village Index Report* released by the New Rural Development Institute of Peking

University in conjunction with Ali Research Institute, 91 of the 100 fastest growing counties in the county digital village index in 2020 are from western China. Gansu ranks among the top five provinces with the fastest development of digital villages: Inner Mongolia (11%), Tibet (10%), Ningxia (10%), Gansu (9%) and Hebei (7%) by growth rate [54].

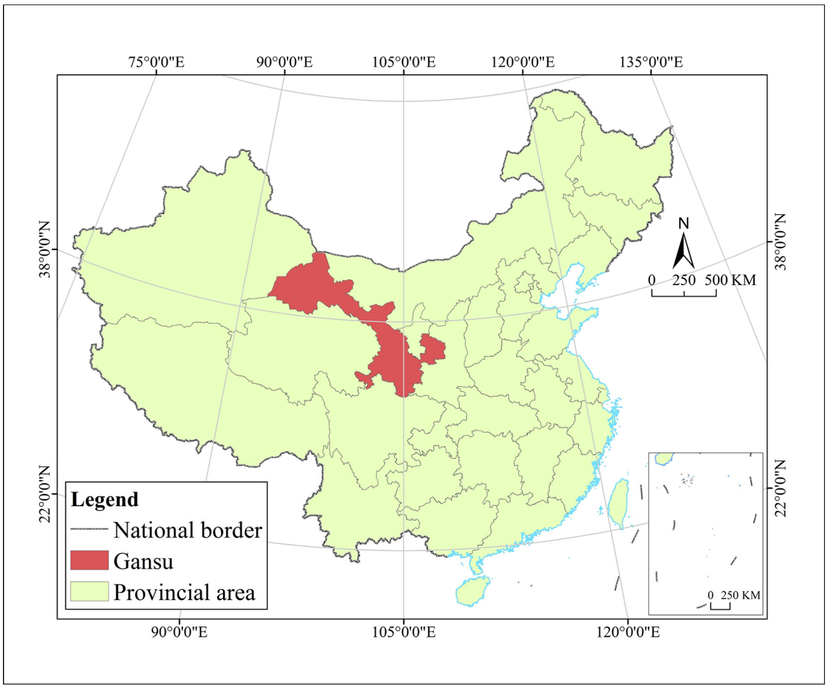

Figure 1. Location of the Study Area.

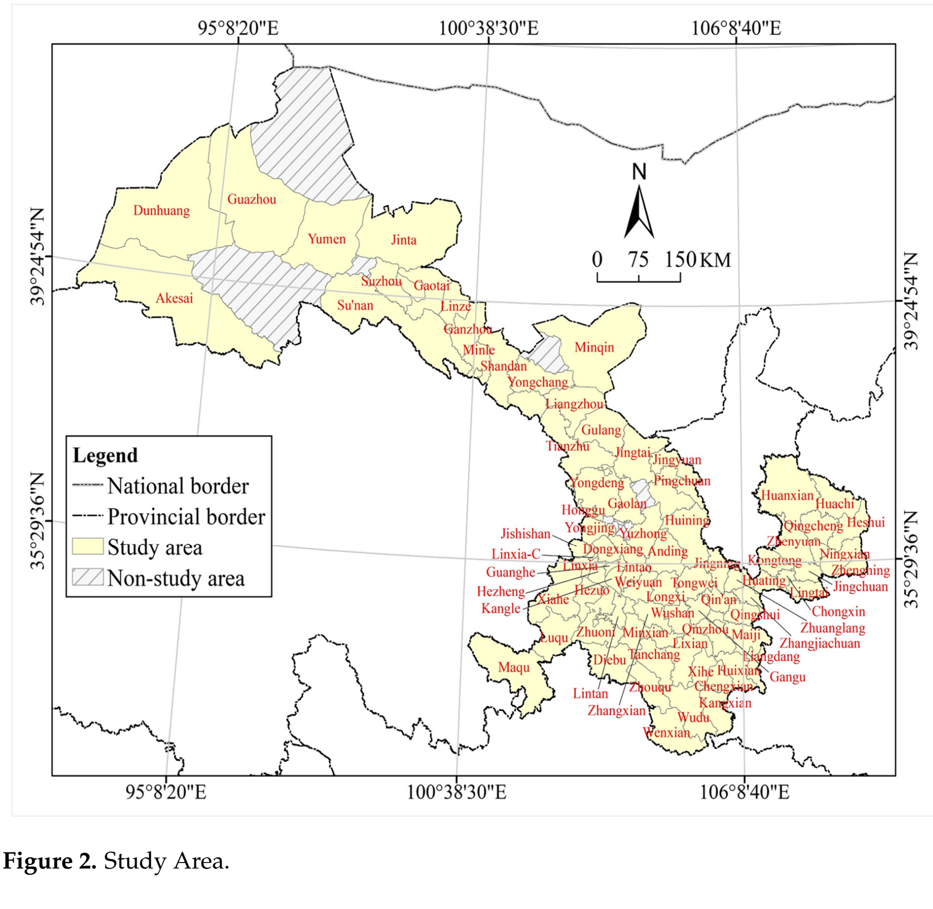

Figure 2. Study Area.

3.2. Research Question, Steps and Methods

The digital village strategy has achieved much after years of implementation, but it also faces great challenges. To accommodate the new development situation, there is an urgent need to optimize the digital village policy. However, there is still a lack of basic and critical knowledge on the level of digital village construction, regional differences and impact mechanisms to provide an adequate basis for the government. Using the Geographic Information System (GIS) and GeoDetector, this paper is dedicated to an empirical study on 79 counties in Gansu, China (including all national digital village pilots in the province) to analyze the level of digital development of villages and the characteristics of regional differences, reveal the influence factors and their mechanisms of action and provide references for the construction of digital or smart villages in China and similar countries around the world. After data collection and preprocessing (as detailed in Section 2.3), the study consists of three processes and five steps (Figure 3).

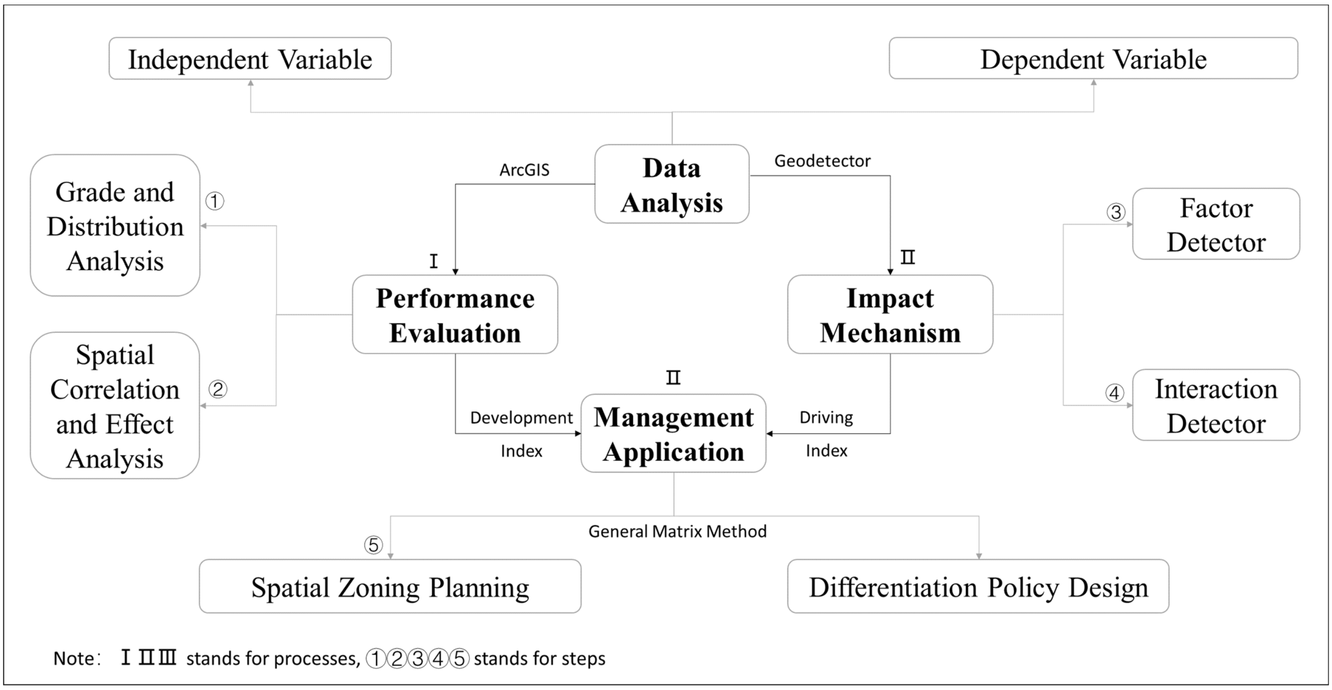

Figure 3. Research steps.

3.2.1. Performance Evaluation and Spatial Characteristics of Digital Village Development

The first process is to analyze the performance and spatial characteristics of digital countryside development in Gansu Province using GIS tools. What are the characteristics of the development and discrepancy of digital villages in different regions? By the spatial analysis method of GIS, we try to evaluate the development level and reveal the spatial differentiation and correlation characteristics of the rural digitalization level and lay the foundation for driving mechanism analysis and policy design.

The first step is to analyze the geographical distribution pattern of the digital rural development index using the spatial clustering analysis tool, which is the most used method for spatial analysis and a nonparametric method that combines statistical principles with graphical means [55]. There are some natural turning points, characteristic points in any statistical series, with which the object of study can be divided into groups of similar nature, so the break points themselves are good boundaries for classification. In the analysis based on GIS, we group the data using the natural breakpoints, and emphasize that the data themselves “speak”, minimizing a priori assumption in rule detection and model construction to better fit the actuality. Compared with other classification methods such as quantile, equal interval and standard deviation, the natural breakpoint method maximizes the difference between different classes and better visualizes the spatial heterogeneity of the digital rural development index.

The second step is to analyze the local aggregation and correlation characteristics of the digital rural development index in space using the spatial hotspot analysis tool to reveal where the clustering of high or low value areas occurs in geographic space [56]. In this paper, we classify the study area into four types of hot, sub-hot, cold and sub-cold areas by Hotspot Analysis Tool, based on the index Getis-Ord G_i^*. The statistical significance of G_i^* is tested using the standardized parameter Z [57,58]. $Z > 2.58$ indicates a hot area, representing the high-value cluster area. That is to say, the high values do not exist in isolation, but that they, as well as the digital rural development indexes of adjacent regions, are in the high value region and can be considered as leaders in the digital development of the villages in the study area. $Z < -2.58$ indicates a cold area, which represents the low-value cluster area. That is, the high values do not exist in isolation, but they, as well as the digital rural development indexes of adjacent regions, are in the low value region and can be considered as laggards in the digital development. The areas with $1.96 < Z < 2.58$ or $-1.96 < Z < 1.96$ are sub-hot or sub-cold areas, indicating that the high and low values are isolated, i.e., the central region has completely opposite attribute values to its surrounding neighbors, and shows central polarization (high in the center and low in the periphery) or collapse (low in the center and high in the periphery). A larger absolute value of the index G_i^* indicates that it is more statistically significant and it is less likely to be randomly distributed. With n representing the number of counties, Y_i and Y_j as the values of the digital rural development index in counties i and j, respectively, $\overline{Y}$ as the mean value of the digital rural development index, W_{ij} as the spatial weight matrix in global spatial autocorrelation, S_0 as the sum of spatial weight matrices and S as the standardization of the digital rural development index, the index G_i^* is calculated as follows [59]:

$$G_i^* = \frac{\sum_{j=1}^{n} W_{ij} Y_j - \overline{X} \sum_{j=1}^{n} W_{ij}}{S\sqrt{\frac{n\sum_{j=1}^{n} W_{ij}^2 - \left(\sum_{j=1}^{n} W_{ij}\right)^2}{n-1}}} \tag{1}$$

$$\overline{Y} = \frac{\sum_{j=1}^{n} Y_j}{n} \tag{2}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} Y_j^2}{n} - \left(\overline{Y}\right)^2} \tag{3}$$

3.2.2. Influencing Factors and Impact Mechanism of Digital Village Development

The second process is to analyze the mechanisms driving the development of digital villages based on the GeoDetector. What factors have influenced the process of the digital and intelligent development of the countryside? GeoDetector is used to quantify the influence of different factors on rural digitization and reveal the interaction and effect between different factors. The analysis of the driving mechanism can be conducted based on GeoDetector [60], Geographically Weighted Regression [61], the Spatial Durbin Model [62] and other methods. GeoDetector is used in this paper, as it allows simultaneous analysis of the direct and interactive effects of the influence factors and fits the needs of this study better than other methods. GeoDetector is a collection of open-source research applications developed by Prof. Wang Jinfeng for measuring spatial heterogeneity, detecting explanatory factors and analyzing interactions between variables (including two versions in Excel and R languages, free to download at http://www.geodetector.cn/, accessed on 12 October 2022) that has been applied in many fields of natural and social sciences. The basic principle of GeoDetector is based on the second law of geography (the Law of Spatial Heterogeneity). It divides the study area into geographic subdivisions in calculation and defines the variance of the digital rural development index within a subdivision smaller than that between subdivisions as spatial stratified heterogeneity.

The third step is to analyze the direct influence of different factors on the development of digital villages by the factor detection tool. The key to digital rural development index factor detection and interaction detection using GeoDetector is to calculate the index q, which represents the heterogeneity of the dependent variable and the influence of the independent variable. The index q represents the direct influence of different factors (such as X_i and X_j) on the digital rural development index in factor detection, which is expressed as q (X_i) and q (X_j)) in this paper. By comparing the similarity in spatial patterns between the influence factors (independent variable, X_i) and the digital rural development index (dependent variable, Y_i), GeoDetector calculates and outputs index q [63] (Figure 4). The maximum value of index q is 1 and the minimum value is zero. A larger index indicates that the factor has a greater influence on the digital rural development index. With h representing the number of zonings of the influence factors in the study area (2–10 in this paper), N_h and N being the number of counties in the area h and the study area, respectively, σ_h^2 and σ^2 as variances of the digital rural development indexes in the area h and the study area, respectively, and SSW being the sum of the variance of the zonings (Within Sum of Squares) and SST being the total variance of the study area (Total Sum of Squares), q is calculated as follows [64]:

$$q = 1 - \frac{\sum_{h=1}^{l} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{4}$$

$$SSW = \sum_{h=1}^{l} N_h \sigma_h^2 \tag{5}$$

$$SST = N\sigma^2 \tag{6}$$

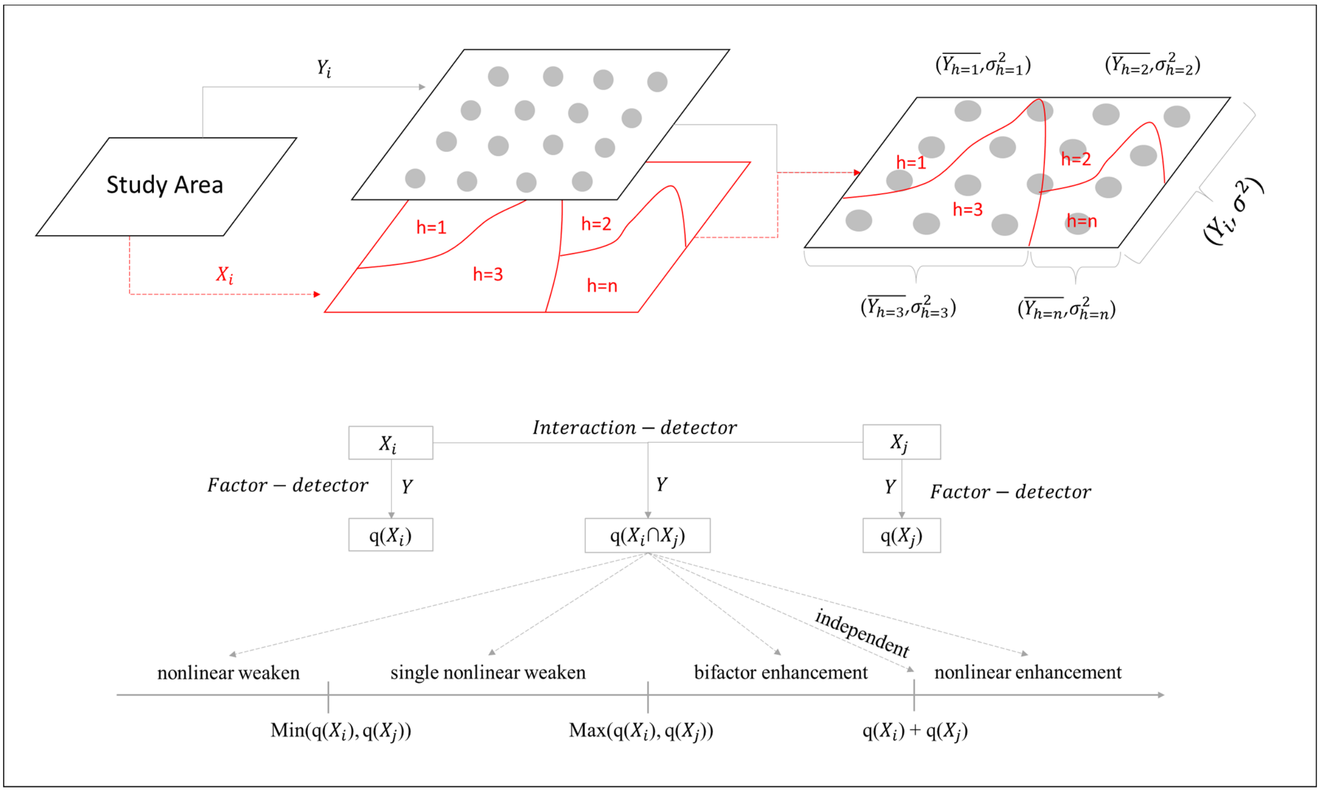

Figure 4. Factor and interaction detector of GeoDetector.

The fourth step is to analyze the combined influence of different factors acting together on the development of digital villages using the interaction detection tool to reveal the interaction relationship between factors. In the interaction detection the index q represents the combined influence of i and j factors when acting together on the digital rural development index, which is expressed in this paper as $q\ (X_i \cap X_j)$. According to the relationship of $q\ (X_i \cap X_j)$ with the minimum direct influence value (Min ($q\ (X_i)$, $q\ (X_j)$), the maximum value (Max ($q\ (X_i)$), $q\ (X_j)$) and the sum value ($q\ (X_i) + q\ (X_j)$), the interactive influence is divided into five classes [65]. Depending on the type of factor-pair interaction, it is possible to determine whether the two factors increase or decrease the influence when they act together. Both nonlinear weaken and single nonlinear weaken represent the presence of an antagonistic effect between different factors, indicating that the driving forces of i and j cancel each other with influence weakened or even disappearing when they act together on Y. The pairing of the two factors should be avoided in policy design. Both bifactor enhancement and nonlinear enhancement represent a synergy effect between different factors, suggesting that the driving forces of i and j reinforce each other with enhanced or even significantly amplified influence when they act together on Y. It is important to induce the pairing of the two in policy design [66,67] (Figure 4).

3.2.3. Management Zoning and Policy Design of Digital Village Development

The third process is to divide the study area into multiple spatial zones and design differentiated management policies by using the general matrix method. How to apply the analysis results to the design process of digital rural development policy? The results of the analysis of the first two problems are coupled using the GE matrix to provide ideas and suggestions for policy design from the perspective of spatial zoning and differentiated management. The last step is to divide the study area into a variety of space partitions by the general matrix method and design targeted and adaptive management policies for each partition. The general matrix method, also known as the nine-quadrant evaluation method, is a portfolio analysis method designed by the General Electric Company in the United States. It evaluates the competitiveness and attractiveness of companies separately based on weighted indices to establish nine combinations and three strategy types. In the study of village digitalization, the development index is chosen to represent the competitive power as the horizontal coordinate, and the driving index is chosen to represent the attractiveness power as the vertical coordinate. The two indices are divided into three levels by the quantile method, thus contributing to nine combinations and three types of policy areas. Targeted and appropriate investment strategies and management policies are designed for each type based on the actual construction and development needs of the digital villages in the policy area (Figure 5).

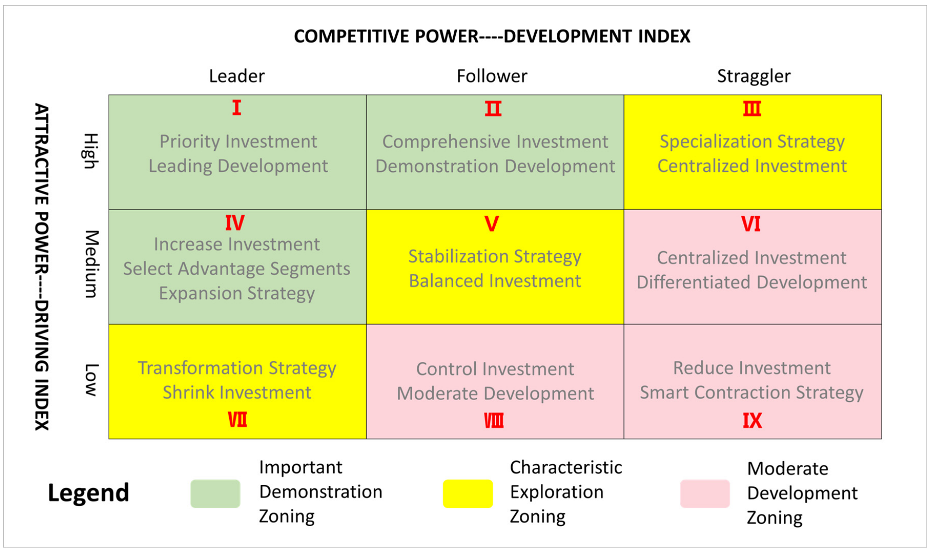

Figure 5. General matrix method.

3.3. Indicator Selection and Data Sources

The Chinese government has not issued an official scheme for measuring the development level of digital villages and constructing an index system [68], although there are two schemes available. The first is that Zhang [69] constructed a provincial digital rural development index and creatively proposed the concept of Digital Rural Development Readiness. It refers to the degree of preparation for the construction of digital villages and puts forward five first-level indexes: macro environment support, general infrastructure support, information environment support, government service environment and application service. The second is China's county-level digital rural development index published by the Institute of New Rural Development of Peking University and the Ali Research Institute. Annual reports for 2018 and 2020 have now been released. The reports focus on evaluation at a county scale, and the report for 2020 provides sample data of 2481 counties (districts or cities), a large proportion of county-level regions in China. The digital countryside index for counties sums up the digital content and specific representations of China's rural infrastructure, rural economy and rural management, and includes specific representational indexes from the perspectives of both producers and consumers, with full consideration of the emerging digital phenomena in current rural development [70]. Moreover, the report represents an aggregate of national macro statistical data, industrial data and Internet big data to measure actual digital rural development more accurately, which has had a great social influence [71].

Therefore, based on the comprehensive consideration of spatial scale, data quality and spatial demand, the indexes in the second scheme are used as research data in this paper. The level of digital village development is represented by the village digitalization index, which is further divided into three key sub-indexes: the village facilities digitalization index, village economy digitalization index and village management digitalization index. All indexes have a value in the range of (1, 100) and a larger value represents a higher level of development [72]. Since the Chinese government has been vigorously promoting the development of "new infrastructure", digital economy and digital government in recent years [73], all four indexes are set as dependent variables.

As there is no specific research on the factors influencing the construction of digital villages at present, it is impossible to draw directly on the research experience of other scholars. We can extract the possible set of influence factors by analyzing the key procedures of digital village construction practice. First of all, both the central government and local governments in China have incorporated the construction of digital villages into the development plans of new urbanization and rural revitalization, and factors related may affect the development of digital villages [74]. Given that urbanization and rural revitalization are complex processes, this paper chooses rural population, urbanization rate, rural consumption, rural resident and per capita income to characterize them, based on the research approach of Xie [75] and Zhang [76]. Secondly, rural digitalization is a new product of the integration of traditional rural development to a certain stage and emerging information technology, so the county's economic development stage and industrial structure will inevitably have a great impact on the rural digitalization process. Following the research approach of Ouyang [77], Li [78] and Zhao [79] et al., this paper chooses to represent the impact of economic and industrial structure and the level of industrialization with Gross Domestic Product (GDP), Secondary Industry Added Value, Tertiary Industry Added Value and GDP Per Capita. Thirdly, the construction of digital villages is still in its early stages, and the government plays a significant role in the process of digitizing villages. Based on the findings of Shen [80] and Chang [81], this paper uses Government Revenue and Fixed Asset Investment to represent the state or potential of government investment in the development of the digital countryside. In summary, this paper constructs a system of indexes applied to driving mechanism analysis from the perspective of urbanization, industrialization and government support using 10 independent variables and 4 dependent variables (Table 2).

Table 2. Variable composition analysis.

Variable	Code	Indicator	Data Source
Dependent	Y_1	Village Digitalization Index	*Index of Digital Rural County, 2020*
	Y_2	Village Facilities Digitalization Index	
	Y_3	Village Economy Digitalization Index	
	Y_4	Village Management Digitalization Index	
Independent	X_1	Rural Population	*Gansu Development Yearbook, 2021* *County Statistical Bulletin, 2020* *Work Report of County Government, 2021*
	X_2	Urbanization Rate	
	X_3	Rural Consumption	
	X_4	Rural Resident Per Capita Income	
	X_5	Fixed Asset Investment	
	X_6	Gross Domestic Product (GDP)	
	X_7	Secondary Industry Added Value	
	X_8	Tertiary Industry Added Value	
	X_9	GDP Per Capita	
	X_{10}	Government Revenue	

Spatial statistical analysis of the dependent variable data using GIS tools was conducted to evaluate the development performance of digital villages in Gansu, and to pro-vide a basis for method selection for driving mechanism analysis by spatial effect detection. The dependent variable data came from the Peking University Open Research Data Platform developed by Prof. Huang Jikun, Director of the Institute for New Rural Development, Peking University, and Mr. Gao Hongbing, Director of AliResearch. By importing the dependent and independent variables into GeoDetector, we explained the driving mechanism of rural digitalization, including the direct influence and indirect interaction effects of factors, and coupled the Development Index (the result of spatial clustering analysis of the dependent variable) and Driving Index (the independent variable based on the weighted sum of driving forces) through the GE matrix to spatially partition the rural digitalization in Gansu and provide a basis for differentiated policy design. Most of the independent variables are from the *Gansu Development Yearbook, 2021*, and those missing are from the *County Statistical Bulletin, 2020* and the *Work Report of County Government, 2021*.

4. Results

4.1. Performance Evaluation and Spatial Effect

This section is mainly to answer the first question (what are the characteristics of the development and discrepancy of digital villages in different regions?) and provide the basis for the selection of driving mechanism analysis methods through spatial effect de-tection. Based on the independent variables (village digitalization index, village facilities digitalization index, village economy digitalization index and village management digitalization index), the study area is classified into leader, follower and straggler types us-ing the spatial clustering analysis tool to evaluate the development level of rural digitali-zation. In addition, the spatial hotspot analysis tool is adopted to detect spatial autocorrelation. If the independent variables are spatially heterogeneous and correlated, the spatial econometric model rather than statistical regression methods should be chosen to analyze the driving mechanisms.

4.1.1. Village Digitalization Index

Linxia had the largest village digitalization index, up to 68.14, while Luqu had the smallest value of 32.72, less than half of the maximum. The average was 47.83, with 50.63% of counties above the average. Linxia, Liangzhou, Yongdeng, Dunhuang, Yuzhong, Jingtai, Kangxian, Xifeng, Suzhou, Kongtong are leaders in the rural digitalization in Gansu Province, dispersed in geographical distribution. It should be noted that the three national pilots, Gaolan in Lanzhou City, Yumen in Jiuquan City and Gaotai in Zhangye City, are not leaders in digital countryside construction, so they need to leverage national investment in future to accelerate development. Yongjing, Huixian, Weiyuan, Jingyuan, Huating, Huining, Liangdang, Qinzhou, Hezuo, Xihe, Ningxian, Ganzhou, Jingning and Gaotai are followers in the digital development of rural areas in Gansu Province, mostly concentrated along the Yellow River and on both sides of the traffic arteries. Kangle, Wenxian, Jishishan, Yumen, Zhangjiachuan, Zhuoni, Sunan, Diebu, Dongxiang, Akesai, Minqin, Xiahe, Maqu and Luqu are stragglers in rural digitalization in Gansu Province, and most of them are autonomous counties of ethnic minorities. The counties lagging behind in the construction of digital villages are all concentrated in the provincial boundary of Gansu Province, especially in the southwestern mountainous areas (Figure 6).

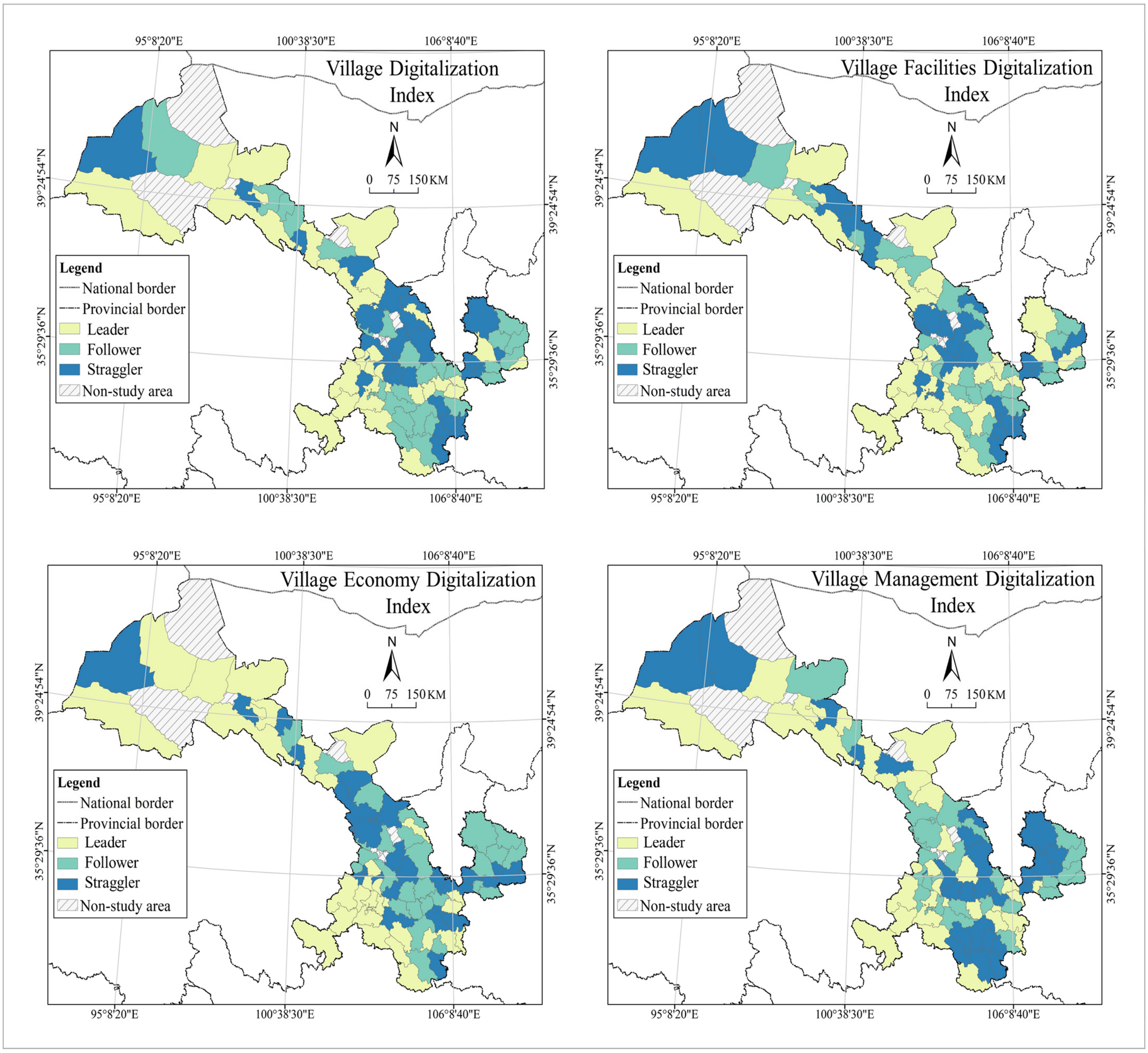

Figure 6. Analysis on development and geographic pattern of village digitalization in Gansu.

By use of the spatial hotspot analysis tool, it can be seen that rural digitalization in Gansu Province shows significant spatial agglomeration and correlation, and the geographical distribution of hot and cold counties shows a "center—periphery" spatial pattern. Guazhou, Shandan, Tianzhu, Jintai, Pingchuan and Yuzhong are hot spot areas, mostly clustered in the provincial capital metropolitan area. Most of the counties of the sub-hot type are concentrated in the periphery of the hot area and extend along the Yellow River to the east and south of Gansu Province. Maqu, Luqu, Zhuoni, Diebu and Xiahe are cold spot areas, all concentrated in the autonomous region of ethnic minorities in the southwest of Gansu Province. About half of the counties of the sub-cold type are distributed in the eastern periphery of the cold spot areas, and the other half are in the Hexi Corridor in northern Gansu Province (Figure 7).

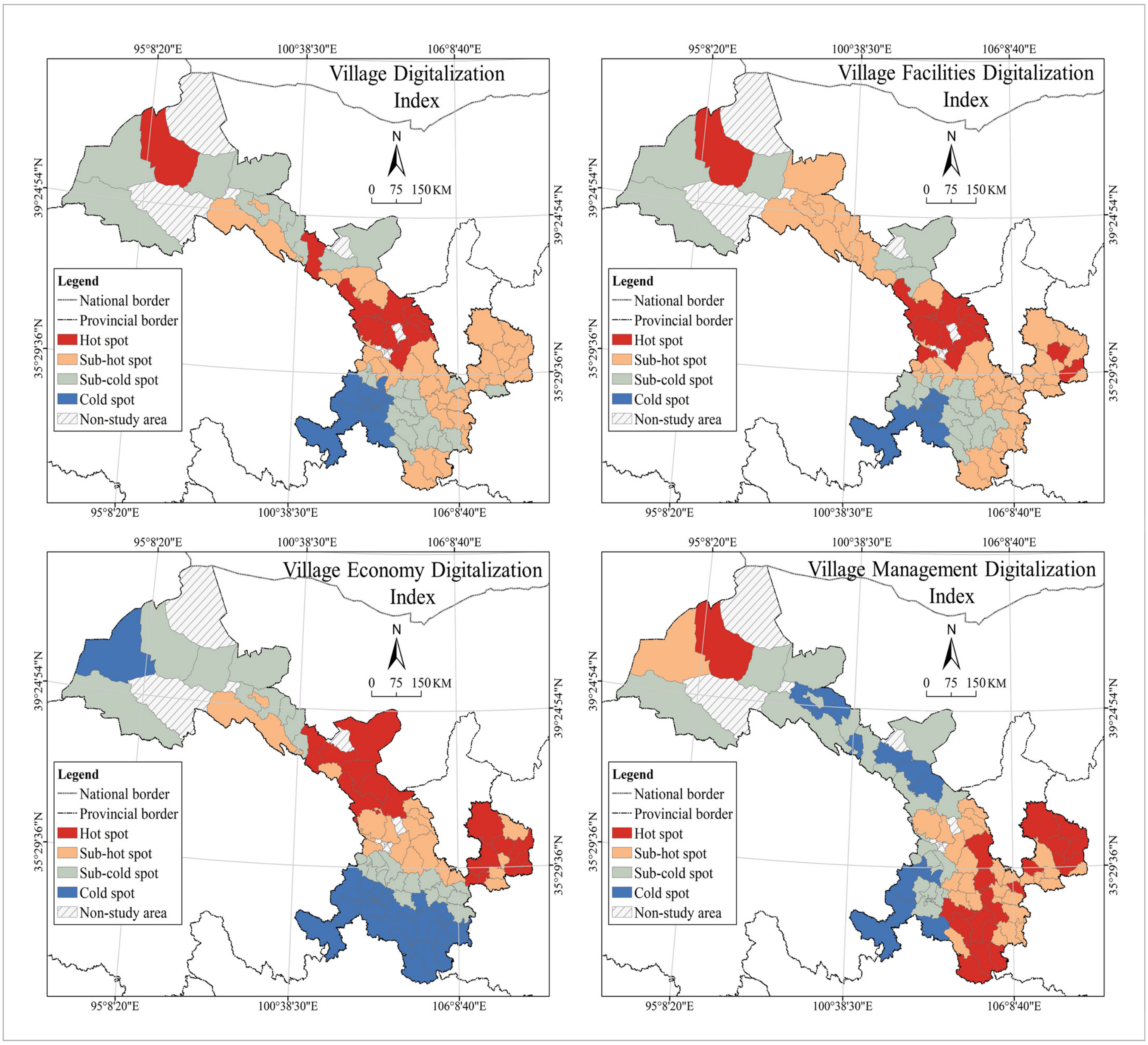

Figure 7. Analysis on spatial effect of village digitalization in Gansu.

4.1.2. Village Facilities Digitalization Index

Linxia had the largest village facilities digitalization index, up to 96.06, while Maqu had the smallest value, only 34.65, differing from the minimum by 2.77 times. The mean value was 67.31, much higher than the village digitalization index, and 51.90% of counties were above the mean. Linxia, Yongdeng, Chongxin, Dunhuang, Gaolan, Yuzhong, Lintao, Liangdang and Honggu are leaders in the digital development of rural facilities in Gansu Province, mostly clustered in the Lanzhou metropolitan area, Tianshui–Longnan metropolitan area and the Hexi Corridor town belt in clusters. Suzhou, Xihe, Jingtai, Longxi, Huining, Jingchuan, Qingcheng, Lingtai, Yumen, Liangzhou, Guanghe, Zhuanglang, Zhengning, Yongchang, Gangu and Qingshui are followers in the digital development of rural facilities, forming four clusters in Dingxi, Jiayuguan, Qingyang and Wuwei. Zhangjiachuan, Minqin, Linxia, Xiahe, Diebu, Dongxiang, Akesai, Luqu and Maqu are stragglers in the digital development of rural facilities, mostly concentrated in the Gannan Tibetan Autonomous Prefecture (Figure 6). In the national pilot project, Gaolan of Lanzhou City and Gaotai of Zhangye City are leaders. In particular, Gaolan ranks fifth and has played a good demonstration role. Yumen of Jiuquan City is a follower, ranking 42nd, and its village facilities digitalization index is only 67.20, still below the average, with a big gap with the predetermined target of the central and provincial governments.

The spatial pattern of cold and hot spots in the village facilities digitalization index in Gansu Province is largely similar to that of the village digitalization index, differing only in some local areas. Most of the hot counties are clustered in the Lanzhou metropolitan area, largely the same as the village digitalization index, and the sub-hot counties are further expanded in Tianshui and the Hexi Corridor. The cold counties are still clustered in the Gannan Tibetan Autonomous Prefecture, but their geographical scope is shrinking, and the counties in the northwest are now sub-cold counties.

4.1.3. Village Economy Digitalization Index

Liangzhou had the largest village economy digitalization index, up to 77.02, while Zhuoni had the smallest value, only 27.29, differing from the minimum by 2.82 times. The average was 36.21, and only 36.71% of counties were above the average. Only Liangzhou, Linxia and Suzhou are leaders in the digital development of the rural economy, and all national pilot counties are not included. Yuzhong, Jingtai, Weiyuan, Kongtong, Guanghe and Yongdeng are followers in the digital development of the rural economy. They are scattered in geographical distribution, mostly in Longnan and Longxi. Dongxiang, Hezheng, Minqin, Zhangjiachuan, Guazhou, Sunan, Gaotai, Tanchang, Akesai, Maqu, Lintan, Diebu, Zhouqu, Shandan, Yumen, Xiahe, Jinta, Wenxian and Zhuoni are stragglers, covering most of Gansu Province.

Unlike the village digitalization index and the village facilities digitalization index, the village economy digitalization index forms two hot and cold spot centers, respectively. The big hot spot center is located in the Jinchang–Wuwei metropolitan area, with sub-hot counties expanding to Lanzhou. The small hot spot center is in the Qingyang–Pingliang metropolitan area. The small and large hot spot centers are connected through the sub-hot spot area. The large cold spot is located in the Gannan–Longnan region, while the sub-cold spots are distributed in a band on its north side. The small cold spot center is located in the Jiuquan–Zhangye region, distributed in a ring-like cluster.

4.1.4. Village Management Digitalization Index

Huanxian had the largest village management digitalization index up to 79.26, while Luqu had the smallest at only 19.48, differing from the minimum by 4.07 times. The average was 50.25, with less than half of the counties exceeding the average. Huanxian, Lintao, Kangxian, Lixian, Huining, Guazhou, Dunhuang, Kongtong, Jingyuan, Tongwei, Longxi, Yongchang and Qinan are leaders in the digital development of rural management in Gansu Province, distributed in clusters in Longnan and in a finger cluster in the Dingxi-Tianshui–Pingliang–Qingyang region. Pingchuan, Guanghe, Jingchuan, Minxian, Lintan, Jingtai, Linxia, Yongdeng, Hezheng, Ningxian, Huixian, Yuzhong, Tianzhu, Zhangxian, Huachi, Yongjing, Heshui and Gangu are followers in the digital development of rural management in Gansu Province, distributed in clusters in the periphery of the leaders and expanding to the Lanzhou–Baiyin integrated development area and the town belt of the Hexi Corridor. Zhangjiachuan, Liangdang, Diebu, Zhuoni, Maqu, Yumen, Akesai, Linze, Gaolan, Shandan, Sunan, Xiahe, Minqin, Kangle and Luqu are stragglers in the digital development of rural management in Gansu Province, clustered in the Gannan Tibetan Autonomous Prefecture and the town belt of the Hexi Corridor (Figure 8). Gaotai of Zhangye City in the national pilot project ranks 14th (61.74), leading the digitalization process of rural management in Gansu Province; however, Yumen of Jiuquan City, ranking 70th (34.69) and Gaolan of Lanzhou City, ranking 73rd (29.16), are both within the top 10 of the bottoms, with insufficient demonstration and leading power for the region.

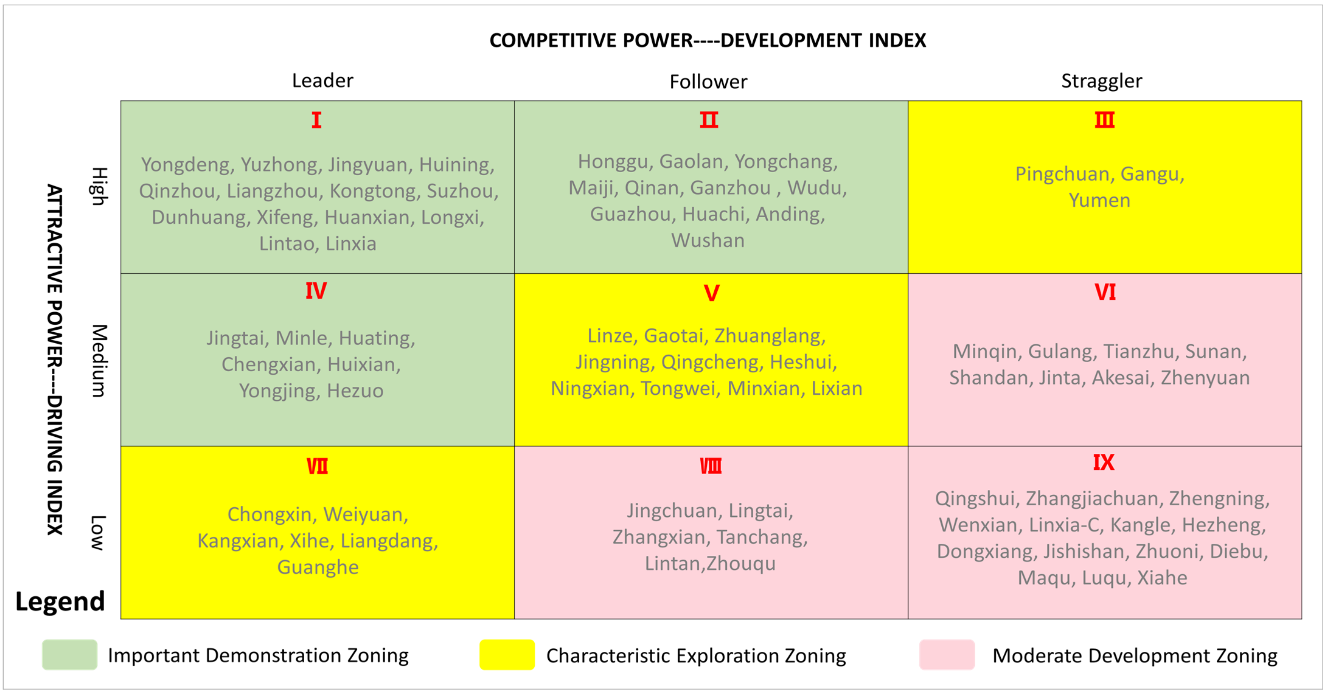

Figure 8. Analysis on spatial zoning of village digitalization in Gansu.

The hot and sub-hot counties are concentrated in the Longnan–Tianshui–Pingliang–Qingyang urban dense area in southeastern Gansu Province, forming a "center-periphery" structure. With Gaotai, Linze, Suzhou, Yongchang, Liangzhou and Gulang counties as the center and Minqin, Jinta, Yumen, Minle, Shanda, and Jingtai counties as the periphery, a cold and sub-cold belt-like agglomeration area is formed in the Hexi Corridor. A cluster agglomeration area of cold and sub-cold counties is formed in Sunan with Maqu, Luqu, Xiahe and Diebu counties as the center and Zhuni, Hezuo, Kangle and Jishishan counties as the periphery.

4.2. Influencing Factors and Impact Mechanism

This section addresses the second question (what factors have influenced the process of digital and the intelligent development of the countryside?) by means of GeoDetector. With the dependent and independent variables imported, the software outputs the q (X_i) and q $(X_i \cap X_j)$ index values to represent the direct and indirect influence of the factor, respectively. In addition, the software also outputs factor interaction types, including nonlinear weaken, single nonlinear weaken, bifactor enhancement and nonlinear enhancement, which are used to determine whether the factor interaction effect is antagonistic or synergistic.

4.2.1. Influence of Factors: Factor Detector

The mean value of the direct influence of the factors is 0.23 and the driving forces of tertiary industry added value, government revenue, fixed asset investment, gross domestic product and secondary industry added value are above the mean. The tertiary industry added value is the most influential, followed by government revenue, far ahead of other factors. Notably, the influence of Rural Resident Per Capita Income is very weak, the direct influence of GDP Per Capita is insignificant (not statistically significant) and the direct influence of Rural Population is only moderately statistically significant. The mean value of the direct influence of the factors is 0.24, and the driving forces of government revenue, tertiary industry added value, secondary industry added value, gross domestic product and fixed asset investment are above the mean. The largest direct influence is found in government revenue while the smallest is found in GDP per capita and is not statistically significant; rural population has a large influence but it is only moderately statistically significant (Table 3).

Table 3. Factor detector of village digitalization in Gansu.

Indicator	Code	Y_1		Y_2		Y_3		Y_4	
		q	p	q	p	q	p	q	p
Rural Population	X_1	0.21	0.08	0.21	0.09	0.10	0.03	0.24	0.04
Urbanization Rate	X_2	0.11	0.05	0.21	0.04	0.05	0.05	0.00	0.60
Rural Consumption	X_3	0.20	0.03	0.23	0.05	0.18	0.04	0.08	0.02
Rural Resident Per Capita Income	X_4	0.05	0.05	0.11	0.02	0.05	0.05	0.05	0.35
Fixed Asset Investment	X_5	0.28	0.02	0.27	0.02	0.25	0.05	0.29	0.02
Gross Domestic Product	X_6	0.27	0.03	0.30	0.02	0.27	0.01	0.32	0.01
Secondary Industry Added Value	X_7	0.25	0.01	0.33	0.00	0.14	0.05	0.02	0.19
Tertiary Industry Added Value	X_8	0.45	0.00	0.35	0.00	0.35	0.00	0.35	0.00
GDP Per Capita	X_9	0.13	0.38	0.02	0.19	0.10	0.37	0.10	0.03
Government Revenue	X_{10}	0.39	0.00	0.37	0.00	0.33	0.01	0.07	0.07

The mean value of the direct influence of the factors is 0.18, and the driving forces of tertiary industry added value, government revenue, gross domestic product, fixed asset investment and rural consumption are above the mean. Both tertiary industry added value and government revenue are far ahead in direct influence, while rural residents' per capita income and urbanization rate rank last. Note that the direct impact of GDP per capita is weak and is not statistically significant. The mean value of the direct influence of the factors is 0.15, and the driving forces of tertiary industry added value, gross domestic product, fixed asset investment and rural population are above the mean. The direct influence of tertiary industry added value is far ahead, while that of rural consumption is very weak and nearly negligible. It is worth noting that government revenue is only moderately statistically significant, while rural resident per capita income, secondary industry added value and urbanization rate are not statistically significant with small direct influence (less than 0.1).

4.2.2. Interaction of Factors: Interaction Detector

There is a significant synergy effect when different factors act together, manifested as bifactor enhancement and nonlinear enhancement. The mean of the interaction effect is 0.59 and 60.00% of the factor pairs are above the mean. In the interaction relationship, 82.22% of the 45 factor pairs show nonlinear enhancement, rural population, urbanization rate, rural consumption, rural resident per capita income, GDP per capita and government revenue as super interaction factors. It is important to note that the factor pairs of gross domestic product ∩ GDP per capita, rural population ∩ government revenue, tertiary industry added value ∩ GDP per capita, tertiary industry added value ∩ rural population and tertiary industry added value ∩ fixed asset investment rank in the top five for the interaction effect (Table 4).

Table 4. Interaction detector of village digitalization index.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	0.21									
X_2	*0.50*	0.11								
X_3	*0.66*	*0.58*	0.20							
X_4	*0.41*	0.13	*0.27*	0.05						

Table 4. *Cont.*

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_5	*0.74*	*0.58*	*0.59*	*0.41*	0.28					
X_6	*0.73*	*0.49*	*0.69*	*0.38*	*0.66*	0.27				
X_7	*0.60*	*0.51*	*0.56*	0.32	*0.67*	0.53	0.25			
X_8	***0.78***	0.55	*0.68*	*0.60*	**0.74**	0.60	0.64	0.45		
X_9	*0.60*	*0.44*	*0.61*	*0.29*	*0.68*	***0.82***	*0.67*	***0.78***	0.13	
X_{10}	***0.80***	*0.51*	*0.66*	*0.47*	*0.69*	*0.70*	*0.68*	0.64	*0.68*	0.39

Note: Italics represent non-linear enhancement of interaction effect, and bold represents the top five in all factor pairs. Tables 5–7 have the same meaning.

The interaction relationships between different factors, super interaction factors and the village digitalization index are largely the same, but there are some differences in factor pair composition and their interaction effects. The mean of the interaction effect is 0.60 and 57.78% of the factor pairs are above the mean. Of the 45 factor pairs, 84.44% show an interaction relationship of nonlinear enhancement, including urbanization rate ∩ rural consumption, rural population ∩ rural consumption, rural consumption ∩ fixed asset investment, rural population ∩ government revenue, rural population ∩ fixed asset investment ranking the top five (Table 5).

Table 5. Interaction detector of village facilities digitalization index.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	0.21									
X_2	*0.68*	0.21								
X_3	***0.79***	***0.80***	0.23							
X_4	*0.46*	0.28	*0.54*	0.11						
X_5	***0.75***	*0.75*	***0.78***	*0.56*	0.27					
X_6	*0.73*	*0.73*	*0.71*	*0.55*	*0.62*	0.30				
X_7	*0.61*	*0.67*	*0.68*	*0.47*	*0.68*	0.57	0.33			
X_8	*0.72*	*0.71*	*0.74*	*0.59*	*0.68*	0.55	0.64	0.35		
X_9	*0.39*	*0.34*	*0.42*	0.13	*0.40*	*0.40*	*0.44*	*0.50*	0.02	
X_{10}	***0.77***	*0.66*	*0.70*	*0.57*	*0.68*	0.67	0.63	0.64	*0.50*	0.37

The interaction between factor pairs is manifested as bifactor enhancement and nonlinear enhancement, while the latter decreases to 66.67%. The mean of the interaction effect is 0.42 and 51.11% of the factor pairs are above the mean. Notably, rural population, rural consumption, gross domestic product, tertiary industry added value and GDP per capita are super interaction factors; fixed asset investment ∩ tertiary industry added value, tertiary industry added value ∩ GDP per capita, fixed asset investment ∩ government revenue, GDP per capita ∩ government revenue, fixed asset investment ∩ gross domestic product is among the top five in interaction force (Table 6).

Table 6. Interaction detector of village economy digitalization index.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	0.10									
X_2	*0.25*	0.05								
X_3	*0.37*	*0.27*	0.18							
X_4	*0.22*	0.08	0.24	0.05						
X_5	*0.47*	0.29	*0.55*	0.30	0.25					
X_6	*0.44*	0.31	*0.53*	*0.35*	***0.61***	0.27				
X_7	*0.36*	0.18	*0.42*	0.16	0.40	*0.45*	0.14			
X_8	*0.47*	0.40	*0.55*	*0.46*	***0.66***	0.50	*0.51*	0.35		
X_9	*0.29*	*0.23*	*0.53*	*0.23*	*0.58*	*0.60*	*0.40*	***0.65***	0.10	
X_{10}	*0.48*	0.38	0.53	0.36	***0.63***	0.50	*0.55*	0.57	***0.62***	0.33

The interaction relationships between different factors, super interaction factors, the village digitalization index and village facilities digitalization index are largely the same, but there are some differences in factor pair composition and their interaction effects. The mean of the interaction effect is 0.38 and 57.78% of the factor pairs are above the mean. A total of 86.67% of the factor pairs show nonlinear enhancement in the interaction, where fixed asset investment ∩ tertiary industry added value, rural population ∩ tertiary industry added value, rural population ∩ fixed asset investment, rural population ∩ gross domestic product, fixed asset investment ∩ gross domestic product rank in the top five in terms of interaction power (Table 7).

Table 7. Interaction detector of village management digitalization index.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	0.24									
X_2	*0.40*	0.00								
X_3	*0.37*	*0.12*	0.08							
X_4	*0.50*	*0.17*	*0.18*	0.05						
X_5	***0.74***	*0.32*	*0.43*	*0.54*	0.29					
X_6	***0.71***	*0.40*	*0.45*	*0.53*	**0.62**	0.32				
X_7	*0.35*	*0.09*	0.09	*0.14*	*0.35*	*0.39*	0.02			
X_8	***0.74***	*0.40*	*0.45*	*0.52*	***0.76***	0.59	*0.40*	0.35		
X_9	*0.43*	*0.16*	*0.23*	*0.23*	*0.55*	*0.51*	*0.23*	*0.50*	0.10	
X_{10}	*0.40*	*0.17*	0.14	*0.23*	*0.44*	*0.44*	0.10	0.44	*0.27*	0.07

The indirect influence minus the direct influence allows for analysis of the net interaction effect of factor pairs. The mean value of the net effect of all factors on the interaction effect calculated represents the degree of synergistic enhancement of the factors. For example, Rural Population has a direct influence of 0.21 on the village digitalization index, and has an interactive influence of 0.50, 0.66, 0.41, 0.74, 0.73, 0.60, 0.78, 0.60 and 0.80 with Urbanization Rate, Rural Consumption, Rural Resident Per Capita Income . . . , Government Revenue, respectively, and the net interaction effects are 0.29, 0.45, 0.2, 0.53, 0.52, 0.39, 0.57, 0.39 and 0.59, with a mean of 0.43 (Table 8). For the Village Digitalization Index and the Village Facilities Digitalization Index, there are significant differences in enhancement of the interactive influence of factors, with GDP Per Capita, Rural Population, Rural Consumption, Rural Population and Urbanization Rate stronger for the former, while Rural Consumption, Rural Population and Urbanization Rate are stronger for the latter. For the Village Economy Digitalization Index and Village Management Digitalization Index the enhancement of all factors is relatively balanced.

Table 8. Average value of factor interaction effect net value.

Indicator	Code	Y_1	Y_2	Y_3	Y_4
Rural Population	X_1	0.43	0.45	0.27	0.28
Urbanization Rate	X_2	0.37	0.41	0.21	0.24
Rural Consumption	X_3	0.39	0.45	0.26	0.20
Rural Resident Per Capita Income	X_4	0.31	0.35	0.21	0.29
Fixed Asset Investment	X_5	0.36	0.38	0.25	0.24
Gross Domestic Product	X_6	0.35	0.31	0.20	0.19
Secondary Industry Added Value	X_7	0.32	0.27	0.24	0.22
Tertiary Industry Added Value	X_8	0.22	0.30	0.18	0.18
GDP Per Capita	X_9	0.49	0.37	0.36	0.25
Government Revenue	X_{10}	0.26	0.28	0.18	0.22

4.3. Management Zoning and Policy Design

This section deals with the third question (how to apply the analysis results to the design process of digital rural development policy) using the GE matrix. To provide a quantitative basis for spatial planning zoning, the 79 counties in the province are classified into nine sub-categories (combinations) and three categories by hierarchical classification (quantile clustering) in the GE matrix, using the development index and the driving index as the horizontal and vertical axes, respectively. According to the national and Gansu digital village construction policies, differentiated policies are designed for the three categories of planning zones based on the rural digital development needs of the study area.

4.3.1. Spatial Zoning Planning

As a backward and underdeveloped region with limited government and social resources, Gansu should adopt an unbalanced development strategy in the initial stage of rural digitalization. In addition, the analysis in Sections 3.1 and 3.2 shows that there are significant spatial heterogeneity and correlation characteristics in the construction of digital villages in the province. Therefore, spatial zoning should be delineated and differentiated management policies should be designed to improve policy adaptability and regional linkage. Gansu should, according to the development base, location conditions and resource endowment of its counties, make scientific planning and the reasonable arrangement of key tasks and projects of digital village construction by zoning and classification to promote the process. Information technology facilities and services should be built according to the development needs of rural areas, farmers and agriculture, while taking measures to prevent image projects and wastefulness.

In this study, the policy partitions are delineated by the general matrix method, where the horizontal coordinates are directly based on the analysis results in Figure 6, while the vertical coordinates are weighted to calculate the driving index. The direct influence (set to zero when not statistically significant) and the interactive influence are given the same weight in the calculation. Tables 2 and 7 are summed up, and then the proportion of each factor is calculated as the weight. Taking the village digitalization index as an example, the direct and interactive influences of X_1~X_{10} are shown in the first column of Tables 2 and 7, corresponding to the total influences of 0.64 (0.21 + 0.43), 0.48 (0.11 + 0.37), . . . , 0.49 (0 + 0.49), 0.65 (0.39 + 0.26), with a sum of 5.72, corresponding to weights of 0.11 (0.64/5.72), 0.08 (0.48/5.72), . . . , 0.09 (0.49/5.72) and 0.11 (0.65/5.72), respectively. For each county, the weighted sum of all impact factors is calculated as the driving index, and quantile clustering is performed for all counties in the study area. By interacting the horizontal and vertical coordinates, all counties in the study area are classified into nine subcategories (combinations) and three categories.

For the village digitalization index, the policy zoning is as follows: 14 counties are in the leader-high (I) combination, i.e., Yongdeng, Yuzhong, Jingyuan, Huining, Qinzhou, Liangzhou, Kongtong, Suzhou, Dunhuang, Xifeng, Huanxian, Longxi, Lintao, Linxia; 10 counties are in the high (II) combination, i.e., Honggu, Gaolan, Yongchang, Maiji, Qinan, Ganzhou, Guazhou, Huachi, Anding, Wushan and Wudu; 3 counties are in the straggler-high (III) combination, i.e., Pingchuan, Gangu and Yumen; 7 counties are in the leader-medium (IV) combination, i.e., Jingtai, Minle, Huating, Chengxian, Huixian, Yongjing and Hezuo; 10 counties are in the follower-medium (V) combination, i.e., Linze, Gaotai, Zhuanglang, Jingning, Qingcheng, Heshui, Ningxian, Tongwei, Minxian and Lixian; 9 counties are in the straggler-medium (VI) combination, i.e., Minqin, Gulang, Tianzhu, Sunan, Shandan, Jinta, Akesai and Zhenyuan; 6 counties are in the leader-low (VII) combination, i.e., Chongxin, Weiyuan, Kangxian, Xihe, Liangdang and Guanghe; 6 counties are in the follower-low (VIII) combination, i.e., Jingchuan, Lingtai, Zhangxian, Tanchang, Lintan and Zhouqu; 14 counties are in the straggler-low (IX) combination, i.e., Qingshui, Zhangjiachuan, Zhengning, Wenxian, Linxia-C, Kangle, Hezheng, Dongxiang, Jishishan, Zhuoni, Diebu, Maqu, Luqu and Xiahe (Figure 8).

The analysis results of the village facilities digitalization index, village economy digitalization index and village management digitalization index are shown in Figures 9–11 (where the images are self-explanatory, and they are not described in detail here so as to control space), which are important references for the planning, design, policy, programming and implementation of digital village construction.

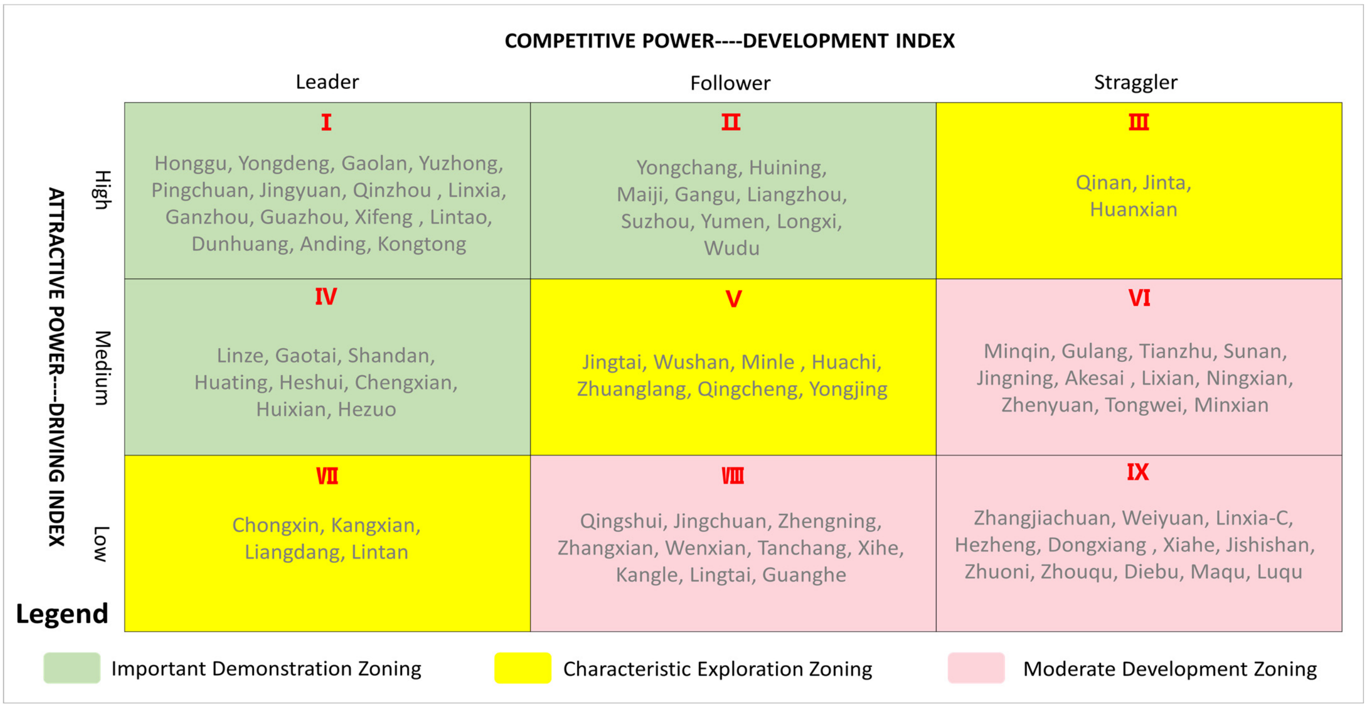

Figure 9. Analysis on spatial zoning of village facilities digitalization in Gansu.

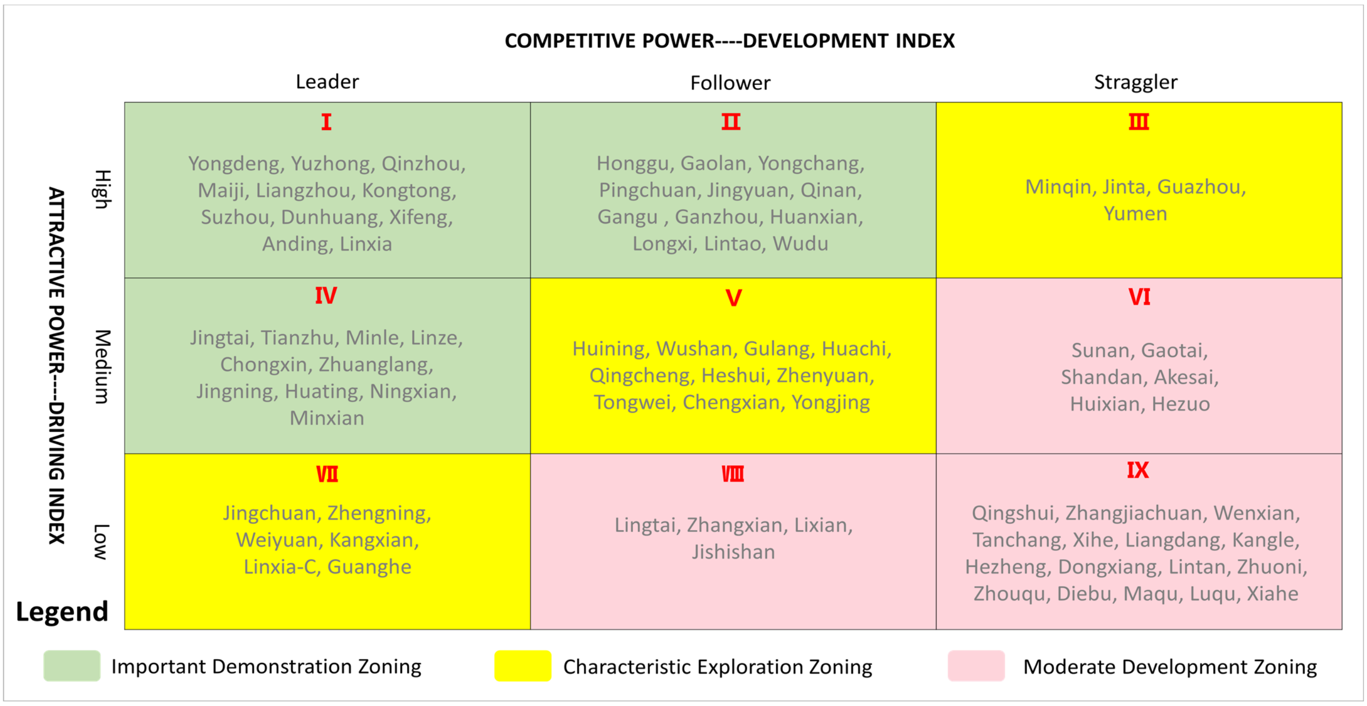

Figure 10. Analysis on spatial zoning of village economy digitalization in Gansu.

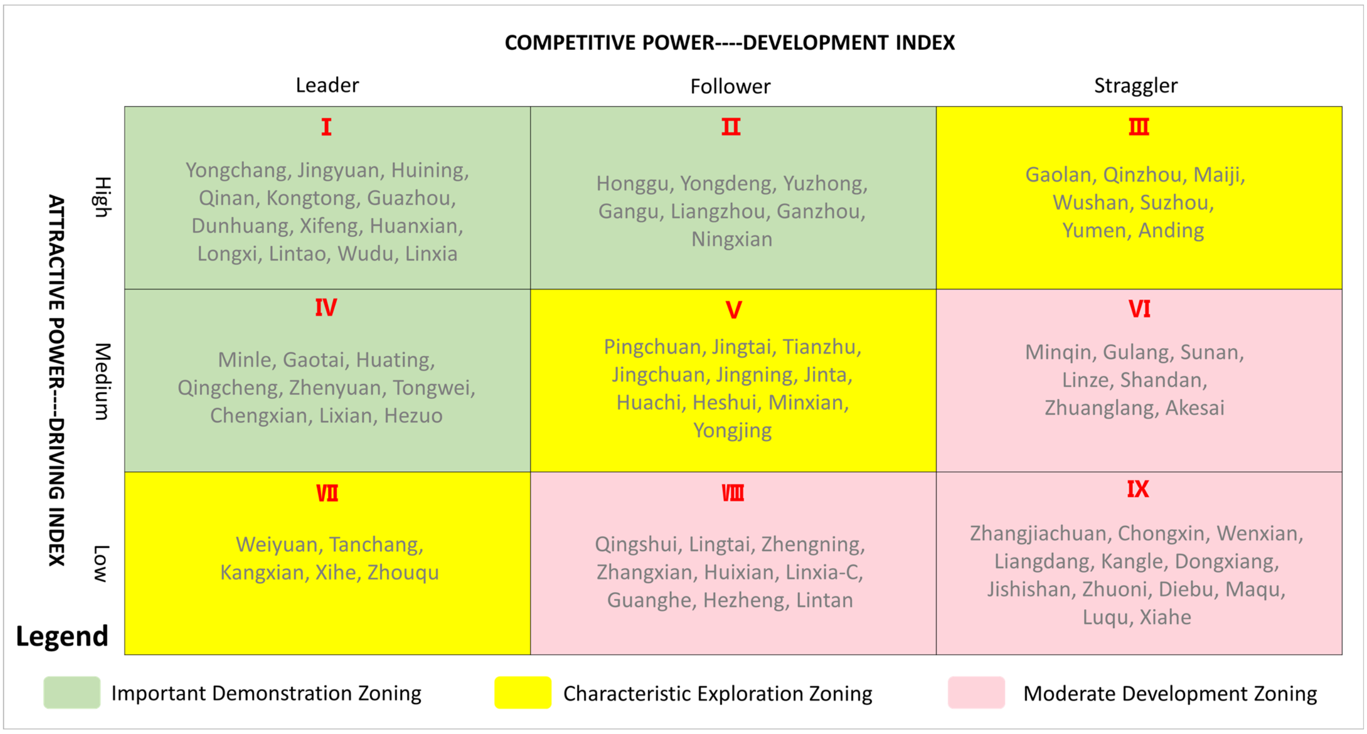

Figure 11. Analysis on spatial zoning of village management digitalization in Gansu.

4.3.2. Differentiation Policy Design

1. Important Demonstration Zoning: Shaping Leadership

The development index and the driving index of rural digitalization in this type of policy area are both high with strong competitive power and attractive power in Gansu. With a promising development and high regional status, they are the priority and focus regions for investment. They should adopt an expansion strategy in the future and try to grow into the leaders of rural digitalization in the province. First, the Gansu provincial government and municipal governments should give more preference to the counties within the policy area in allocating funds, capital and resources for rural digitalization. Second, all counties in this policy area should, in accordance with the people-oriented and bold innovation idea, give full play to the main role of farmers to stimulate the enthusiasm, initiative and creativity of farmers, so that the majority of farmers become participants and beneficiaries of the construction of the digital countryside. They should further boost the passion for digital development of agricultural enterprises in terms of the goal of agricultural and rural modernization, help and encourage farmers and agricultural enterprises to apply the new generation of information technology, cultivate new business forms and new models of the rural digital economy and drive the overall innovation of the rural development system, mechanism and model. Third, the counties within this policy area should have a sense of responsibility and mission to develop standards for the construction of digital villages in Gansu. It is necessary to develop guidelines or norms for digital rural construction in Gansu based on its own development stage and actual conditions as well as the experience of other provinces. Fourth, it is necessary to guide Gansu to establish early a dynamic monitoring mechanism for the development of digital villages, strengthen the management and supervision of the implementation process and carry out evaluation and guidance for the construction of digital villages.

Of note is that in the process of implementing the expansion strategy, the strategic focus of digital village construction is not exactly the same for counties in the three combinations of I, II and IV. The counties in Combination I should adopt an overall leading development strategy and enjoy priority in capital and resource allocation to promote their long-term leadership in the rural digitalization of Gansu. The counties in Combination II should adopt a model development strategy and increase overall investment to prompt them to become specialized or all-round emerging leaders in the rural digitalization of Gansu. For counties in Combination IV, a strategy of expansion in a dominant segment should be adopted, and according to the results of the analysis in Figures 9–11, increased investment should be made in a certain dominant segment to maintain the position. In general, a digital countryside development model that matches the knowledge structure of the rural population should be established for the three combinations to promote information construction in fields such as rural economy, politics, culture, society, ecological civilization and party construction as a whole, to help revitalize the countryside and move forward the construction of "digital Gansu" by creating a digital countryside brand and image of Gansu as an endorsement pilot.

2. Characteristic Exploration Zoning: Highlight Specialty

Since the development index and driving index of rural digitalization in this policy area are at a midpoint, limited funds, capital and resources should be invested in specialized and characteristic fields for the needs of rural areas, farmers and agricultural development in the future. First, Figures 8–11 are overlaid for analysis to determine the areas of strength for each county in the policy area. Second, a development strategy suitable for specialization, stabilization and transformation is determined based on their resources and conditions. It should be noted that transformation can be considered as a special type of specialized development strategy. Specialization requires establishing strengths and further focusing on their advantages, while transformation requires making up for weaknesses and overcoming the shackles and constraints of weaknesses on the development of strengths.

Gangu and Kangxian should adopt a stabilization strategy because they have the same combination of facilities, economy and management digitalization index and a very balanced development in all areas. Pingchuan, Yumen, Linze, Gaotai, Zhuanglang, Jingning, Qingcheng, Heshui, Ningxian, Tongwei, Minxian, Lixian and Chongxin should adopt a specialization strategy. For example, for Zhuanglang and Jingning, their village digitalization indexes are in Combination V, their facilities digitalization indexes are in Combinations V and VI, their economy digitalization indexes are in Combination IV and their management digitalization indexes are in Combinations VI and V, respectively. Obviously, they have significant advantages in the field of rural economy digitalization and a specialization strategy should be adopted for them to further highlight their advantages and shape their own characteristics in the future. Weiyuan, Xihe, Liangdang and Guanghe should adopt a transformation strategy as they have significant lagging areas and no prominent areas of strength. In Liangdang, for example, there is no prominent strength with the village digitalization index and facilities digitalization index in Combination VII, and a serous lag with the economy and management digitalization index in Combination IX. Therefore, if additional investments are made in infrastructure informationization in the future, it is probable that the returns will hardly achieve the expected goals, and it is recommended to shift future investments of funds, capital and resources to the areas of economic and managerial digitization that are seriously lagging behind to eliminate their constraints on the development of facilities and overall digitization.

For specialization and transformation development, targeted strategies should be adopted to rapidly expand the strengths or make up for the weaknesses. For example, in the development of the digital economy relying on the agricultural products of Taobao Village, live streaming village and Internet celebrity, it is necessary to deepen e-commerce into the countryside, unblock the channel of industrial products to the countryside and promote the online purchase of daily necessities, agricultural materials and tools, the production and operation services of rural residents, besides efforts to promote the sale of agricultural products online and accelerate the construction of logistics facilities for processing, packaging, cold chain transport, storage and delivery to cities of agricultural products. For example, when relying on the digital platform for village self-governance, it is required to carry forward the practice of villagers' online deliberations and online supervision, promote more village high-frequency government affairs and villagers' services to be performed online and by cell phone, and establish electronic ledgers for village assets and finances.

3. Moderate Development Zoning: Enhancing Foundation

Since the policy area has a low competitive power and attractive power of rural digital development, a smart contraction strategy should be adopted to improve the efficiency of capital and resource utilization. For Qingshui, Zhangjiachuan, Zhengning, Wenxian and other counties in Combination IX, it is difficult to change their current status in the short term due to their low level of development and weak power. They should make good use of policy and transfer funds from higher level governments in the future according to the basic needs of national and local (provincial and municipal) governments to accelerate the pace of the digital transformation of rural infrastructure and enhance the foundation and capacity of digital rural construction. For example, they should improve the survey and statistics of the basic data of rural roads and update electronic maps regularly to raise the level of informationization of comprehensive supervision of rural roads. Moreover, they should accelerate the digital transformation of rural power grids and implement rural power grid consolidation and upgrading projects to make up for and strengthen the weaknesses of rural power grids.

Wushan, Minqin, Gulang, Tianzhu, Shandan and other counties in Combination VI should implement differentiated development strategies and concentrate their limited resources. For example, Tianzhu has a very low index of facilities and management digitalization (the former in Combination VI and the latter in Combination V), but it has a high economy digitalization index (in Combination IV) with a high potential and strong driving force for digital economy development, so it should concentrate its limited resources into digital economy development in the future. For example, it should accelerate the development of e-commerce for agricultural products and agricultural supplies and its supporting system, preferably by planning and creating a number of Taobao Villages, live-streaming villages and Internet celebrity agricultural products. Jingchuan, Lingtai, Zhangxian, Tanchang, Lintan and Zhouqu, counties in Combination VIII, should implement an appropriate development strategy. For example, Zhouqu, located in an autonomous region of ethnic minorities and a high mountain valley area, has a complex topography, frequent natural disasters and lagging economic development. Zhouqu currently has a very low index of facilities (in Combination IX), economy (in Combination IX) and management (in Combination VII) digitalization. Zhouqu should control the quantity and distribution of digital countryside investments around national policies and local characteristics in the future and make clever use of limited resources to ensure that it does not fall behind in the wave of rural digitalization in Gansu. For example, it should respond to national policy requirements to overcome school networking difficulties, optimize the construction of education information technology infrastructure, achieve full broadband network coverage in rural elementary schools and township primary and secondary boarding schools and promote the full popularization of online teaching in all schools across the county. Moreover, it should explore the regional and humanistic characteristics of Zhouqu, organize the census of Tibetan cultural resources, the protection and utilization of traditional villages and historical and cultural towns, the digitalization of intangible cultural heritage and explore the construction of a "digital cultural relics resource library", "digital exhibition hall", "intelligent cultural station" and "digital bookstore".

5. Discussion

5.1. Development Characteristics

The development of the digital countryside in Gansu Province is characterized by prominent inequalities, with significant clustering and correlation features. Geographically, the level of digital development in rural Gansu Province varies widely in space and shows significant imbalance. The digital development of rural villages in ethnic minority autonomous regions is seriously lagging behind, and the leading and demonstration role of the national pilot counties remains to be enhanced. From the perspective of fields, the construction of the digital countryside in Gansu Province is not synchronized in different dimensions. For example, the digital infrastructure is in a leading position, while the development of the digital economy is lagging behind. In terms of spatial effects, cold and hot spots are distributed in bands or clusters, forming a "center-periphery" spatial structure and pattern geographically.

The development of digital villages and smart villages is currently on the rise, and multi-scale studies at national, provincial and county levels are constantly emerging. Although it lags behind the development of digital cities and smart cities [82,83], it has become a new hot spot in academia, government and society [84,85]. The unequal development process of rural digitalization is a universal phenomenon due to the large differences in development environment, resource conditions, investment and support, start-up time and construction mode in different regions [86,87]. As more new generation information technologies such as Internet, big data and cloud computing have been applied to the construction of digital villages and new rural infrastructure in recent years, digital, networked, intelligent and smart rural development has accelerated significantly, narrowing the digital divide between urban and rural areas. For example, the use of the Beidou System and artificial intelligence for the scientific management of crops can improve management efficiency; furthermore, with the help of two-dimensional code technology, we can achieve the full traceability of agricultural products from the field to the table, and with the help of e-commerce and live broadcast platforms we can improve the sales numbers of agricultural products and enlarge geographical sales scope.

Some of the findings of this paper corroborate the study conclusions available. At the national scale, Rey-Alvite [88] found through an empirical study of 28 EU countries that there are large differences in smart village development goals, needs, current progress and characteristics, and that there is still a long way to go for a balanced development of digital and smart villages. Li [89] analyzed the opportunities and challenges facing the digital development of infrastructure and public services in rural America and proposed strategies for narrowing the smart divide in rural areas. At the provincial scale, Adamowicz [90] found through the empirical study of the provinces of Poland that there are large inter-provincial differences in the development of smart villages and that some provinces are already at risk of being marginalized. Zhu [91] conducted an empirical test on the level of digital rural development in China's provinces and found that there are very large regional differences and spatial autocorrelations, forming a decreasing spatial pattern of "east-middle-west".

Although this study is based on the county scale, its conclusions are generally consistent with their analysis results. Besides the difference in research scales, this paper further decomposes the village digitalization index into a village facilities digitalization index, village economy digitalization index and village management digitalization index. It also grades and partitions the level of digital development of villages, which significantly improves the fineness and accuracy of the study and is more valuable for the theoretical evolution and practical development of digital villages and smart villages.

5.2. Dynamic Analysis

In terms of the range of direct influence of the factors, rural consumption, fixed asset investment, gross domestic product and tertiary industry added value are all-purpose factors, and they have significant influence on the digital rural development index in all dimensions. Rural population and government revenue are also all-purpose factors, but the former has only moderate statistical significance on the village digitalization index and village facilities digitalization index, and the latter has only moderate statistical significance on the village management digitalization index. Urbanization rate, rural resident per capita income and secondary industry added value are multifunctional factors, which have significant influence on the village digitalization index, village facilities digitalization index and village economy digitalization index, but not on the village management digitalization index. Gross domestic product per capita is a single function factor and has no significant influence on all dependent variables except for the village management digitalization index.

As for the intensity of the direct influence of the factors, the factors can be classified into three categories by overlay analysis of multiple dimensions. With index q that is not statistically significant set to zero, the average of multiple dimensions of the digital rural development index is calculated and ranked according to their direct impact. Tertiary industry added value, gross domestic product and government revenue all have a direct influence close to or above 0.3, and they are key factors. Urbanization rate, rural resident per capita income and GDP per capita all have a direct influence less than 0.1, mostly negligible, and they are auxiliary factors. Fixed asset investment, rural population, secondary industry added value and rural consumption have a direct influence between the key factor and the secondary factor, and they are important factors.

The interaction of factor pairs is dominated by nonlinear enhancement and supplemented by bifactor enhancement. The synergistic effects of the factor driving mechanism are very complex. In addition to the auxiliary factors such as urbanization rate, rural resident per capita income and GDP per capita, which mainly rely on interaction effects to exert indirect influence, the interaction effects of key and important factors such as tertiary industry added value and secondary industry added value should also not be ignored. The factors such as tertiary industry added value, rural population, urbanization rate, rural consumption, rural resident per capita income, GDP per capita and government revenue play the role of super-interaction factors in different dimensions of rural digitalization. The interactive influence between factors cannot be ignored, even for factors with weak direct influence, because it reaches 1–4 times the direct influence in combination with the interactive influence of synergistic factor pairs. Therefore, to achieve the best results in policy implementation, different resources and measures should be matched and combined according to the interaction of factor pairs in the future policy design.

This paper is original in its study of the factors influencing rural digital development and their interactive effects, and some of the aforementioned views are supported by some scholarly papers. According to the global samples (non-China), Chinn [92] argued that per capita income, international trade, urbanization rate, infrastructure, regulatory quality and other economic and social indicators are the determinants of national digital development differences. Park [93] analyzed the characteristics of digital inequality in rural Australia and argued that factors such as population, education level and employment status exacerbate the digital divide in rural development. They found that farmers' income, urbanization rate and rural population have a great influence on the construction of digital villages, which is largely similar to the findings of this paper. However, their study is at the national scale and does not match the needs of local government policy design. Moreover, there is no sufficient discussion on whether the forces of these factors are influenced by scale effects and whether it also applies to the county scale prior to this study.

In the empirical study of China, Ma [94] and Leng [95], at the national scale, concluded that government credit support and farmers' income growth have a significant positive impact on the adoption of digital technologies for rural development. Li [96] found significant spatial heterogeneity, agglomeration and correlation in digital rural development at the provincial scale in China, with population density, industrial structure and economic development having a significant influence on them. Zhao [97] argued that the development of digital villages in Chinese counties significantly contributes to farmers' household consumption. Su [98], based on micro-survey data from national digital village pilot counties in Sichuan, Chongqing and Ningxia, found that farmers in less economically developed and poverty-stricken areas have a low willingness to build digital villages, with lagged participation rates in rural digitalization. Zhang [99] found a significant positive mediating effect of farmers' income on digital village development based on a survey of 164 administrative villages in Zhejiang Province. Despite the differences in research scale and sample geography, government support, farmers' income, economic base, industrial structure and demographic characteristics are found to have a general influence on the construction of digital villages in China.

5.3. Governance Enlightenment

In the context of the current new wave of technological revolution, rural areas should not be left behind in digitalization, urbanization, industrialization and agricultural modernization [100]. Given that it has become a consensus that digitalization and intelligence are the key ways to achieve sustainable development in rural areas [101], the government should strengthen top-level design and planning guidance by developing proper work programs and action plans. In terms of government management and policy design, Gansu's experience has reference value for other provinces in China and other countries in the world. The national digital village development strategy requires the government of Gansu to develop a digital village construction work plan for the province, and the city and county governments to develop digital village construction action plans at the county level according to demand. The provincial government should set provincial digital village pilot counties in all prefecture-level cities according to the level of digital development of villages in the work program and action plan. Depending on the resource base and development needs, each prefecture-level city should have two to five counties. In addition, each county should select two to three towns or three to five villages in the administrative region as county-level pilot areas for the fine implementation of the work. In addition, efforts should be made to formulate differentiated policies for different types of villages such as those clustered and upgraded, integrated with suburban areas, under characteristic protection and relocated and merged, in strict accordance with the rural revitalization strategy and the development support strategy for ethnic minority areas in the pilot selection, with full consideration of the influence and interaction of different factors to accelerate the overall development of rural digitalization in Gansu Province.

It is important to note that the digital development capacity and potential of different regions vary widely [102], so zoning plans should be developed and implemented according to the level of development and its driving mechanisms to effectively improve policy precision and effectiveness [103]. First, the important demonstration zoning counties should maintain their current development trend and promote the interactive construction of digital villages, digital cities and smart cities [104]. Second, the characteristic exploration zoning counties should find the bottleneck of digital rural development, develop special measures to drive digital facilities, digital economy, digital management and digital life, and try to improve the quality of digital development. There are also many problems for the better developed areas of economic and managerial digitization. For example, the county government tends to implement a unified digital platform in all villages, while the villages are passively "involved" or "participate" in the process, with a variety of the platform functions contrary to the actual needs of rural development [105]. Therefore, it is necessary to investigate and analyze villagers' demands and interest gambling in the future and comprehensively optimize and enhance the functions of rural digital platforms accordingly to improve the speed and quality of rural digital governance and digital economy development [106,107]. Third, the moderate development zoning counties are priority areas for government intervention, especially the minority autonomous regions. Undeveloped infrastructure, insufficient human resources and the lack of diverse industrial structures pose great challenges the construction of digital villages in ethnic minority agglomerations, requiring both the central and local governments to increase investment and support to minority communities and autonomous regions in the future [108]. More economically underdeveloped places have slower rural digitalization processes, and lower levels of digitalization will lead to further marginalization. Digital villages and economic development may form a vicious circle [109]. Therefore, for these counties with weak self-generating capacity, especially poverty alleviation or poverty return prevention, the construction of digital villages should be combined with economic development and a focus on the digitalization of infrastructure, industry and consumption to put the development of villages in a virtuous cycle [110].

6. Conclusions

With the development of urbanization, global rural construction is faced with severe challenges such as population loss, economic depression, facility and building decay, ecological and environmental pollution. Rural digitalization is a new means to deal with these problems and is also the key to rural transformation and sustainable development [109]. In this paper, based on the case study of 79 counties in the Gansu Province of China, we analyze the level of digital development of rural areas in less developed regions of the country and its driving mechanism based on a combination of GIS tools and GeoDetector. The conclusions are presented as below:

(1) In view of the uneven development of rural digitalization, differentiated policies should be developed in accordance with zoning planning and spatial governance. By regional heterogeneity, the 79 counties are divided into leader, follower and straggler levels according to the gap of the digital rural development index among different counties. By domain heterogeneity, the development of digital applications in different dimensions is out of sync, with the village facilities digitalization index in the leading position, the village management digitalization index in the middle and the village economy digitalization index lagging behind.

(2) Due to the significant spatial agglomeration in the development of digital villages, the government should strengthen top-level design while insisting on regional linkage and joint governance. Rural digitalization shows characteristics of spatial correlation and spillover to the periphery. The hot, sub-hot, cold and sub-cold regions are distributed in bands or clusters, forming a spatial pattern of "center-periphery".

(3) The direct influence of different factors varies greatly, and the factor pair driving mechanism is complex. From the perspective of the scope of action, they can be divided into all-purpose factors (e.g., gross domestic product), multifunction factors (e.g., secondary industry added value) and single-function factors (e.g., GDP per capita); from the perspective of intensity of action, they can be divided into key factors (e.g., tertiary industry added value), important factors (e.g., rural population) and auxiliary factors (e.g., urbanization rate). The factor pair interactions are dominated by nonlinear enhancement and supplemented by bifactor enhancement, with very complex synergistic effects and driving mechanisms. Therefore, efforts should be made to drive the rational combination of different resources and measures in future policy design based on the direct influence and interaction of factors.

The biggest innovation in this paper is the systematic analysis of the factors influencing rural digitization and reveals the interaction between different factors. This study focuses on the county scale and further decomposes the village digitalization index into three sub-indexes to provide more granular analysis. The digitalization of villages is a new trend in global development, and the research methods and analysis results of this paper are applicable not only to China but also to similar countries around the world. As mentioned above, the United States, the United Kingdom, Romania, India, Australia and the European Union all face challenges similar to China's in rural development, such as stagnant or regressive rural development and population loss. These countries and regions are now working to explore and experiment with a variety of solutions using digital tools to leverage sustainable rural development, and this paper will provide a valuable reference for them.

This paper also has some limitations, such as the use of cross-sectional data in the study. Although Peking University released data for both 2018 and 2020, differences in the index system for calculating the index in different years as well as significant missing data for the study area in 2018 (excluding data for municipal districts) resulted in the inability to conduct panel analysis, which may affect the accuracy of the analysis results. Regardless, this paper has taken the first step to explore the driving mechanism of rural digitalization, which will be of great benefit to the future emergence of high-quality theoretical research and practical solutions.

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