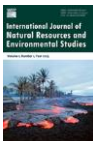
WEP
Warwick
Evans
Publishing

International Journal of Natural Resources and Environmental Studies
ISSN: 3006-2012 (Print), ISSN: 3006-0834 (Online) | Volume 8, Number 4, Year 2026
DOI: https://doi.org/10.62051/ijnres.v8n4.04
Journal homepage: https://wepub.org/index.php/IJNRES/index



Path Dependence and Transformation Mechanisms in Resource-Depleted Cities from a Resilience Perspective: The Case of Jiaozuo City

Ran Huang

School of Surveying and Land Information Engineering, Henan Polytechnic University, Jiaozuo, 454000, China

ABSTRACT

Urban transformation is a critical development issue facing resource-depleted cities. Examining the mechanisms and driving factors of such transformation from a resilience perspective is of great significance for achieving high-quality development in resource-based cities. This paper constructs an urban resilience measurement index system based on four dimensions—economic, social, engineering and ecological—and employs the entropy method and Partial Least Squares (PLS) to conduct a quantitative assessment of Jiaozuo City's urban resilience across different dimensions and phases from 2000 to 2021. The results indicate that: (1) Jiaozuo's urban resilience underwent three phases—low resilience (2000–2007), moderate resilience (2008–2015) and high resilience (2016–2021)—with its resilience level exhibiting a 'slow–rapid–slow' upward trend. (2) Between 2000 and 2021, the driving factors behind Jiaozuo's resilience evolution shifted gradually from economic resilience indicators and innovation-related indicators within social resilience to a combined drive from resilience indicators across all dimensions. Among these, factors such as the foundation of regional development, the level of openness to the outside world, innovative development, government management and the ecological environment were key drivers of Jiaozuo's resilience evolution. Based on the identified primary drivers of resilience and applying the theory of evolutionary economic geography, this study summarises the transformation mechanisms to provide a reference for the transformation of other resource-depleted cities, thereby facilitating the cultivation of new-quality productive forces in such cities.

KEYWORDS

Resource-depleted cities; Resilience; Path dependence; Transformation mechanisms; Jiaozuo City.

1. INTRODUCTION

The world is undergoing a period of profound change unseen in a century, with the economic outlook continuing to deteriorate. How to enhance cities' resilience, recovery capacity and adaptability in the face of unknown risks has become a major challenge in the field of urban governance [1]. The Outline of the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Long-Range Objectives Through the Year 2035 explicitly states the need to transform urban development models, enhance urban governance standards and build resilient cities; the development of urban resilience has thus been elevated to a national strategy.

Resilience can currently be interpreted from three perspectives: firstly, resilience within the framework of 'pan-governmentalism', which, drawing inspiration from ecological science, employs an adaptive cycle model to understand regional resilience; secondly, resilience viewed through the lens of path dependence, where the resilience approach based on path dependence relates to resilience resistance and recovery [2]; thirdly, the resilience of complex adaptive systems theory, with systems ontology having gained prominence in regional resilience analysis in recent years [3]. Evolutionary economic geography interprets resilience as the capacity of various regional elements to continuously adjust their structures in response to changes in the internal and external environment in order to achieve co-evolution, reflecting the interactive effects between the system's intrinsic properties and external risks. Urban resilience is a highly complex, coupled system comprising human and environmental systems such as the urban economy, society, institutions, ecology and infrastructure. It refers to the capacity of the urban system to adapt, recover and learn in the present and future when facing various disturbances, such as natural and man-made disasters. This process emphasises the joint participation and multi-stakeholder collaboration of residents, communities, businesses, government bodies and non-governmental organisations (NGOs) [4].

Research on resilience in China has primarily focused on conceptual analysis, measures of resilience and influencing factors. Furthermore, scholars have predominantly assessed regional resilience at the national, river basin, provincial, urban agglomeration and rural levels. Research on resource-based cities, however, has centred on the following areas: firstly, studies on the development pathways, driving factors and mechanisms, and policy evolution and outcomes [5] of the transformation of resource-based cities; secondly, the performance characteristics and evaluation methods of the economic transformation of resource-based cities, as well as the impact of transfer payments, institutional evolution and environmental regulations on the economy. Research on resilience in other countries has centred on resilience theory, the identification and classification of resilience, safety management tools, impact analysis, risk assessment and training [6]. As resilience research continues to develop, some scholars have shifted their focus to the study of shocks, arguing that the nature of external shocks is of significant importance for understanding regional resilience; for example, the socio-spatial characteristics, scale, duration, depth and impact on target populations of such shocks [7]. Research on the transformation of resource-based cities has centred on social and psychological issues in such cities [8], demographic characteristics [9], the life cycle of mining areas [10], economic structural transformation [11], and transformation models [12].

Although there has been a wealth of research on the transformation of resource-depleted cities, existing studies have largely focused on economic, industrial and green transformation, with insufficient in-depth analysis of the cities' overall transformation; criteria for selecting indicators to measure urban resilience remain inconsistent, making it difficult to compare the resilience of different cities; there is a lack of interpretation of resilience from the perspective of complex systems theory, and few studies have constructed multi-dimensional indicator systems for evaluation; Research into the transformation pathways of resource-based cities has largely been summarised at a macro level, based on resource types (coal, forestry, petroleum, etc.) and developmental stages (growth, maturity, decline, regeneration), with a lack of study on the transformation pathways of specific case areas, resulting in insufficient enhancement of the transformation capacity of resource-depleted cities. Cities are both complex mega-systems and products of historical evolution. As the developmental conditions of each city vary, it is more valuable to study the changes in resilience and the transformation pathways of individual cities than to analyse the differences in development trajectories and resilience between cities at a macro level. Path dependence and lock-in, as terms in evolutionary economic geography, hold significant theoretical importance in explaining phenomena such as the positive lock-in brought about by increasing returns to emerging industries and the negative lock-in leading to the decline of resource-based old industrial areas. Breaking free from the shackles of negative lock-in and creating new growth pathways essentially amounts to enhancing adaptive resilience. How do resource-depleted cities break free from path dependence to forge new pathways? What are the primary drivers and mechanisms of their transformation? These questions require further investigation. Consequently, this paper constructs a measurement system for the level of urban resilience in Jiaozuo City across four dimensions: 'economic resilience, social resilience, engineering resilience, and ecological resilience'. Using resilience as a method and medium, and applying the theories of evolutionary economic geography, the study examines path dependence, lock-in and path creation in Jiaozuo, a resource-depleted city, It quantitatively explores the evolutionary patterns of urban resilience, identifies dominant driving factors and distils transformation mechanisms, investigates specific pathways for Jiaozuo's urban transformation, and explains the 'Jiaozuo phenomenon', thereby providing a reference for Jiaozuo to achieve green, high-quality development and for the transformation of other resource-depleted cities.

2. DATA SOURCES AND RESEARCH METHODS

2.1. Data sources

Located at the junction of Henan and Shanxi provinces, Jiaozuo is rich in mineral and tourism resources. It is one of the first cities in China to be designated as a resource-depleted city, a regional central city within the Central Plains Urban Cluster, and a key node in Henan Province's high-speed rail network. The primary indicator data used in this study are derived from the 《China Urban Yearbook》 (2001–2022), the《Henan Statistical Yearbook》, the《Jiaozuo Statistical Yearbook》, and the 《Jiaozuo Municipal Bulletin on National Economic and Social Development》. Where data for certain indicators were missing for specific years, the average growth rate or the mean value of adjacent years was used to estimate the figures.

2.2. Research Methods

A city is a complex, coupled system in which any single subsystem can influence changes in urban resilience; consequently, it is necessary to establish an evaluation framework for urban resilience levels across four dimensions: economic resilience, engineering resilience, social resilience and ecological resilience. Using Partial Least Squares (PLS) and path dependence theory, this study analyses the long-term temporal evolution of Jiaozuo City's resilience from 2000 to 2021, identifies the key driving factors across each dimension, and explores the specific pathways and mechanisms underpinning the city's urban transformation.

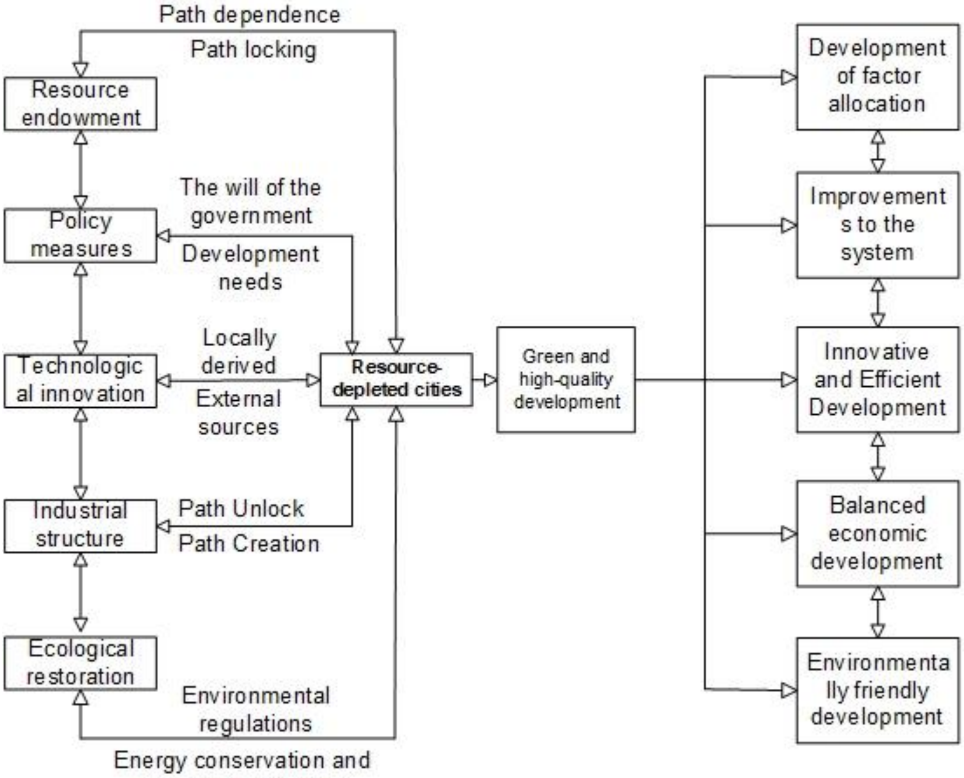


Figure 1 Analytical framework for the transformation mechanisms of resource-depleted cities from a resilience perspective

2.2.1. Development of an Urban Resilience Indicator System for Jiaozuo City

Currently, comprehensive urban resilience evaluation systems are predominantly established based on dimensions such as infrastructure, economy, society and ecology [13], whilst some scholars have conducted research based on dimensions including economy, ecology, society, infrastructure and institutions. Drawing on relevant research findings, and taking into account Jiaozuo City's unique characteristics and the challenges it faces, a city resilience evaluation system for Jiaozuo City has been constructed by selecting 50 secondary evaluation indicators across four dimensions: economic, social, engineering and ecological resilience. The scores for resilience across each dimension are summed using the entropy weighting method to calculate the comprehensive resilience score.

Economic resilience refers to an economic system's ability to adapt in the short term to shocks and to develop new growth trajectories in the long term. Vigorously developing the tourism industry, utilising foreign investment and expanding foreign trade can stimulate economic vitality, enhance market potential and provide greater resilience against external shocks. Fiscal self-sufficiency, disposable income and fixed asset investment can effectively enhance the level of regional economic resilience. Industrial transformation and structural upgrading in resource-depleted cities are the only way to achieve faster and better development; therefore, indicators such as the share of GDP accounted for by the secondary and tertiary sectors, and the share of GDP accounted for by the output value of the mining and manufacturing industries have been selected.

Urban resilience is manifested in the ability to safeguard residents' livelihoods and ensure the normal functioning of the city when faced with the impact of extreme events, arising from the increased pressure on urban infrastructure due to rising population density. Sudden events such as torrential rain, flooding and earthquakes cause severe damage to infrastructure including power supply, water supply, drainage and roads; therefore, enhancing the resilience of these systems is a key component of building urban resilience. Consequently, indicators such as per capita water supply, electricity consumption and road area have been selected.

Social resilience refers to the ability to maintain the normal functioning of social systems in the face of uncertain natural or man-made risks. Whether natural disasters or sudden public health emergencies such as the COVID-19 pandemic, these events pose enormous challenges to healthcare provision and the standard of public services. Another aspect of social resilience involves addressing issues affecting people's livelihoods, ensuring the equitable distribution of public resources, and maintaining social order. Urban unemployment rates and the proportion of workers across different sectors provide an effective reflection of the distribution of social resources.

Ecological resilience refers to the scale, scope of services and spatial distribution of a city's ecological infrastructure, as well as its capacity to support human resource consumption. As a city with depleted coal resources, Jiaozuo faces significant pressures regarding ecological conservation and pollution control. To comprehensively assess Jiaozuo's ecological resilience from the perspectives of pollution emissions and treatment, as well as ecological green spaces, indicators such as the sewage treatment rate, industrial fine particulate matter emissions and green coverage rate in built-up areas have been selected for analysis.

Table 1: Indicator System and Weightings for the Assessment of Urban Resilience in Jiaozuo City

dimension	Indicators	weight	Properties	dimension	Indicators	weight	Properties
Economic	X1 Tourism revenue	0.0267	+	Society	X27 University students	0.0143	+
Resilience	X2 Total trade value	0.0159	+	Resilience	X28 R&D personnel ratio	0.0183	+
0.3531	X3 Actual FDI	0.0325	+	0.2608	X29 Innovation expenditure ratio	0.0130	+
	X4 Total population	0.0150	+		X30 Urban unemployment rate	0.0133	-
	X5 GDP	0.0232	+		X31 Doctors (per 100,000)	0.0149	+
	X6 Fiscal self-sufficiency rate	0.0200	+		X32 Hospital beds (per 100,000)	0.0304	+
	X7 GDP per capita	0.0230	+		X33 Pupil-teacher ratio (primary & secondary)	0.0151	+
	X8 Savings balance per capita	0.0265	+		X34 Secondary sector employment ratio	0.0166	+
	X9 Secondary industry share	0.0094	+		X35 Tertiary sector employment ratio	0.0285	+
	X10 Tertiary industry share	0.0304	+		X36 Mining employment ratio	0.0154	-
	X11 Mining output share	0.0167	-		X37 Manufacturing employment ratio	0.0235	+
	X12 Manufacturing output share	0.0121	+		X38 Transport & postal employment ratio	0.0329	+
	X13 Per capita disposable income	0.0234	+		X39 Public administration employment ratio	0.0169	+
	X14 Market potential	0.0265	+		X40 Grain production	0.0078	+
	X15 Fixed asset investment per capita	0.0287	+	Ecological	X41 Total energy consumption	0.0235	-
	X16 New industrial electricity use	0.0232	+	Resilience	X42 Sewage treatment rate	0.0137	-
Engineering	X17 Water supply per capita	0.0234	+	0.1712	X43 Wastewater discharge	0.0094	-
Resilience	X18 Electricity consumption per capita	0.0230	-		X44 Electricity consumption per GDP	0.0154	+
0.2149	X19 Buses	0.0205	+		X45 Built-up area green coverage rate	0.0092	-
	X20 Mobile phone subscribers	0.0187	+		X46 SO_2 emissions	0.0143	+
	X21 Internet users	0.0381	+		X47 Domestic waste sanitary treatment rate	0.0082	+
	X22 Per capita road area	0.0086	+		X48 Industrial solid waste utilization rate	0.0234	+
	X23 Road passenger turnover	0.0147	+		X49 Industrial particulate emissions	0.0371	-
	X24 Road freight turnover	0.0399	+		X50 Green space area	0.0169	+
	X25 Drainage pipe density in built-up areas	0.0135	+		X27 University students		
	X26 Social security expenditure ratio	0.0146	+				

2.2.2. Evaluation methods

(1) The entropy method

The data processing steps employed in this indicator system, including the entropy method and weighting, are as follows:

First, each secondary indicator is standardised to eliminate units.

Positive indicators: $$X'_{ij}=\frac{x_{ij}-\min(x_{1j},\ x_{2j},\ \ldots\ldots,\ x_{nj})}{\max(x_{1j},\ x_{2j},\ \ldots\ldots,\ x_{nj})-\min(x_{1j},\ x_{2j},\ \ldots\ldots,\ x_{nj})} \tag{1}$$

Negative indicators: $$X'_{ij}=\frac{\max(x_{1j},\ x_{2j},\ \ldots\ldots,\ x_{nj})-x_{ij}}{\max(x_{1j},\ x_{2j},\ \ldots\ldots,\ x_{nj})-\min(x_{1j},\ x_{2j},\ \ldots\ldots,\ x_{nj})} \tag{2}$$

Here, X'_{ij} denotes the standardised value of indicator j, x_{ij} denotes the value of indicator j for the i-th sample in the original data, and $\min\ x_{ij}$ and $\max\ x_{ij}$ denote the minimum and maximum values of the j-th factor, respectively.

Secondly, calculate the sample weights. Calculate the proportion of the i-th sample under the j-th indicator.

$$P_{ij}=\frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}},\quad 1\leq j\leq m \tag{3}$$

Third, calculate the entropy value of the jth indicator.

$$e_j=-K\times\sum_{i=1}^{n}\left(P_{ij}\times\ln(P_{ij})\right) \tag{4}$$

Here, $K=\frac{1}{\ln(n)}$, where n is the sample size.

Fourth, calculate the coefficient of variation for the jth indicator. The information utility value of an indicator is determined by the difference between the number 1 and the information entropy e_j of that indicator. This difference has a direct impact on the indicator's weight. The greater the information utility, the greater the weight, and the greater the importance of the indicator in the evaluation. The formula for the coefficient of variation is given in Equation (5).

$$d_j=1-e_j \tag{5}$$

Fifth, calculate the weights of the evaluation indicators. The weight of the jth indicator is:

$$w_j=\frac{d_j}{\sum_{j=1}^{m} d_j} \tag{6}$$

Sixth, calculate the overall score for each sample.

$$Z_i=\sum_{j=1}^{m} w_j x_{ij} \tag{7}$$

(2) Partial Least Squares (PLS)

Partial Least Squares (PLS) regression combines the advantages of principal component analysis, correlation analysis and multiple linear regression, and is effective in addressing the issue of multicollinearity among variables; it also offers good interpretability for analytical models with small sample sizes [35]. PLS regression can be used to obtain the Variable Importance in Projection (VIP) index, calculated using the following formula:

$$VIP_j=\sqrt{p\sum_{k=1}^{ncomp}\left(PV_k\times\left(W_{jk}/\|W_k\|/\sum_{k=1}^{ncomp} PV_k\right)\right)} \tag{8}$$

In the formula: VIP_j represents the importance of the jth predictor variable; generally, a VIP > 1 indicates a strong explanatory power, 0.5 < VIP < 1 indicates moderate explanatory power, and VIP < 0.5 indicates weak explanatory power; p represents the number of predictor variables; $ncomp$ represents the matrix of the response variable and predictor variables; w denotes the weights of the response variable; and PV_k represents the variance of the kth component explained by the response variable Y. This study employs variable projection importance to measure the explanatory power of each driving factor on comprehensive resilience, thereby identifying the primary driving factors behind the evolution of comprehensive resilience in the study area.

3. RESULTS AND DISCUSSION

3.1. Characteristics of the temporal evolution of urban resilience in Jiaozuo City

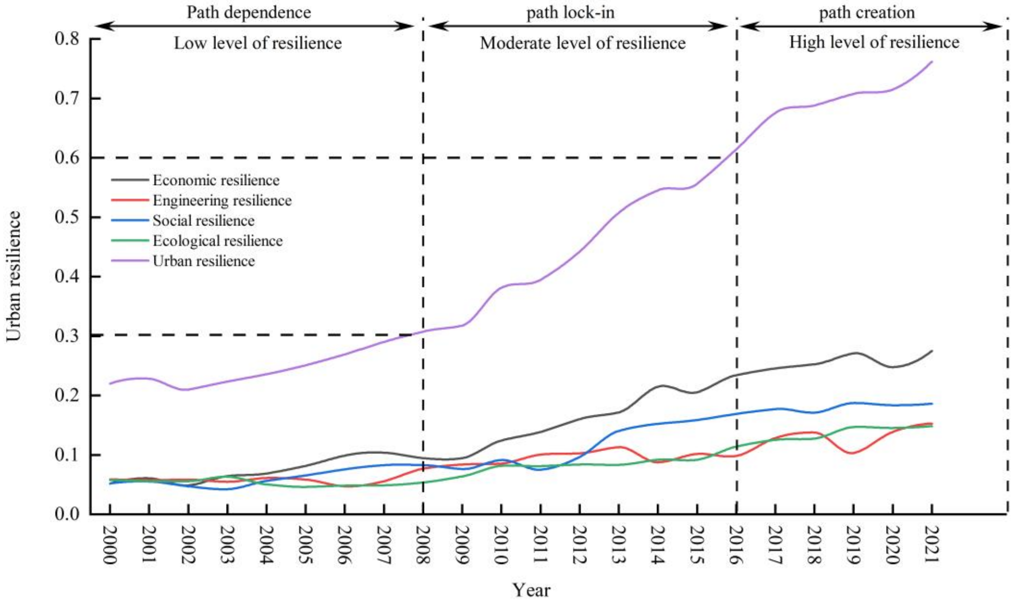


Figure 2: Evolution of Jiaozuo City's Resilience, Related Policies and Development Pathways, 2000–2021

Based on the urban resilience evaluation framework developed, the changes in resilience indicators across various dimensions for Jiaozuo City from 2000 to 2021 are presented (Figure 2). Using the resilience scores for Jiaozuo City calculated via the entropy weighting method, the evolution of the city's resilience is divided into the following periods: the low-resilience period from 2000 to 2007 (0.22–0.29), the moderate resilience period from 2008 to 2015 (0.31–0.56), and the high resilience period from 2016 to 2021 (0.61–0.76). It is evident that Jiaozuo City's urban resilience level has shown an overall upward trend, rising from 0.22 to 0.76 over the 22-year period, with an average annual increase of 0.025. This indicates that the efforts to build a resilient city and the urban transformation in Jiaozuo have yielded significant results.

Figure 2 shows that the development of Jiaozuo City's economic, social, engineering and ecological resilience is positively correlated with the city's overall resilience; the resilience of each system has improved to varying degrees, continuously evolving towards a higher level of resilience. In 2003, economic resilience began to rise as the tourism industry took off, playing a leading role in driving the city's transformation. The outbreak of the 2008 financial crisis led to a slight decline in economic resilience; however, in the same year, Jiaozuo was selected as one of the first batch of resource-depleted cities, receiving national policy and financial support, which mitigated the impact to some extent. In 2015, the state introduced new development concepts, and stricter environmental regulations had a certain impact on economic development.

3.2. Analysis of the Driving Factors Behind the Evolution of Urban Resilience in Jiaozuo City

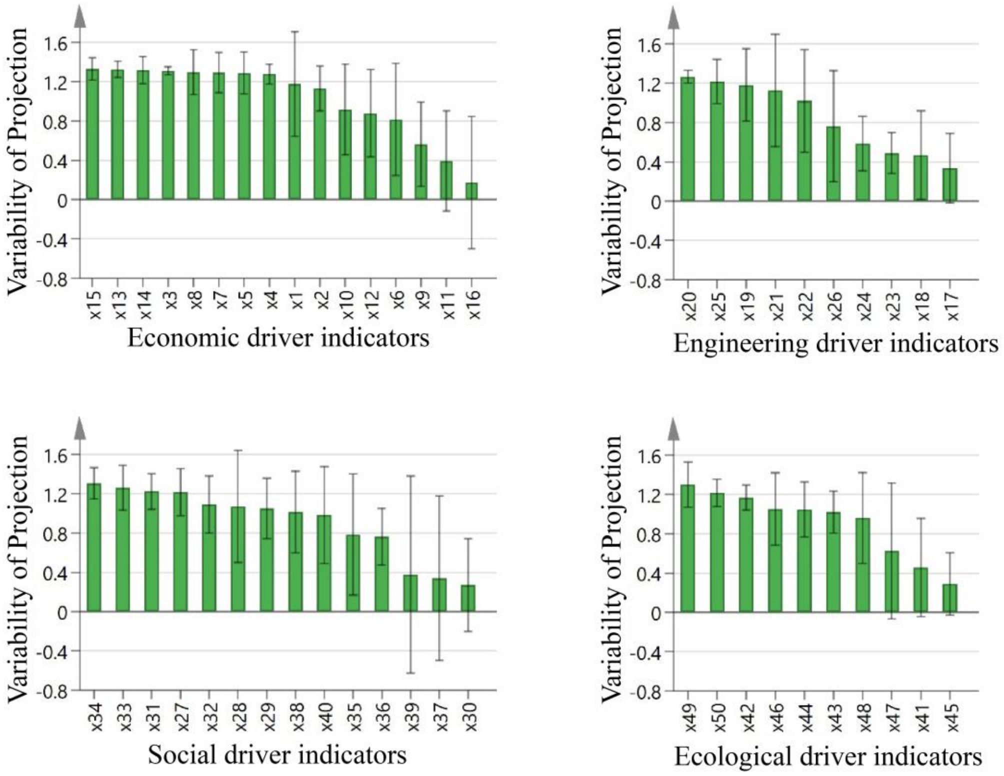


Figure 3: Projected importance of driving variables for urban resilience in Jiaozuo City, 2000–2021

The results indicate that the driving forces of resilience variables across all dimensions are significant; however, economic resilience indicators such as market potential, per capita disposable income and per capita fixed asset investment are the primary drivers influencing the growth of overall resilience. The simulation results show that the predicted value of the dependent variable (R2VY) is 0.9954, and the explained value of the independent variables (R2QY) is 0.9934; that is, the difference between the simulated and predicted values is less than 0.01, indicating that the overall model performs well and is suitable for PLS analysis. In terms of overall explanatory power, from 2000 to 2021, indicators such as market potential, per capita disposable income, per capita fixed asset investment, actual utilised foreign direct investment, number of hospital beds per 10,000 people, industrial particulate matter emissions, number of mobile phone subscribers, proportion of employees in the tertiary sector, number of doctors per 10,000 people, drainage pipe density in built-up areas, green space area, and number of university students per 10,000 people (VIP > 1.2), indicating that Jiaozuo City demonstrated strong resilience across all four dimensions during its evolution from low to high resilience. At the indicator level, the evolution of comprehensive resilience was primarily driven by factors such as market scale, residents' risk-bearing capacity, innovation capacity, infrastructure development, and the ecological environment. Furthermore, indicators such as the proportion of employees in public administration and social security, per capita water supply, green coverage rate in built-up areas, urban unemployment rate, and new industrial electricity consumption exhibit relatively weak driving effects (VIP < 0.5), suggesting that social security services, water supply, and electricity infrastructure remain key factors influencing the enhancement of Jiaozuo's comprehensive resilience.

4. CONCLUSIONS

This paper takes Jiaozuo City as its subject of study to examine the patterns, characteristics and driving factors of its resilience evolution, and to identify the mechanisms of transformation from the perspective of evolutionary economic geography. The findings reveal that:

(1) Jiaozuo City has undergone three distinct phases: a period of low resilience (2000–2007), a period of moderate resilience (2008–2015), and a period of high resilience (2016–2021). Its resilience levels exhibited an upward trend characterised by 'slow—rapid—slow', whilst the urban system underwent a life cycle of 'decline—stability—recovery—enhancement'. During the study period, the city faced shocks such as the financial crisis, the introduction of new development concepts, and the COVID-19 pandemic. Empirical research indicates that industrial transformation and upgrading in resource-depleted cities is a viable approach to enhancing urban resilience and achieving green, high-quality development.

(2) The driving factors behind Jiaozuo's resilience evolution vary according to the stage of transformation. In the initial phase, resource depletion compelled a shift towards tourism and the tertiary sector; innovation drove social resilience, though ecological pressures remained. In the middle phase, supported by policy, the economic structure was optimised, high-tech industries emerged, living standards improved, and the ecological situation began to show signs of recovery. In the later phase, ecological governance proved effective, infrastructure required further enhancement, the economy shifted towards high-quality development, the industrial structure became balanced, education was optimised, and overall resilience was strengthened.

(3) The 'Jiaozuo Phenomenon' refers to the transformation pathway for resource-depleted cities that involves leveraging their geographical location and the locational advantages of their cultural and tourism resources to improve the image of the 'coal city', whilst developing a diversified industrial base encompassing chemical manufacturing, automotive components, cultural tourism and transport.

REFERENCES

[1] GuanW.H.,Xu,H.,Wu,W.et,al.(2024).Comprehensive urban resilience and dynamic prediction of Nanjing Citybase d on the new development concept. Scientia Geographica Sinica, 44(04):681-692, https://doi.org/10.13249/j.cnki.sgs.20221098.

[2] Simmie, J., & Martin, R. The economic resilience of regions: Towards an evolutionary approach. Cambridge Journal of Regions, Economy and Society., 3(1), 27–43.

[3] Welsh, M. Resilience and responsibility: Governing uncertainty in a complex world. The Geographical Journal, 180(1), 15–26.

[4] Zhao R.D., Fang C.L.,Liu H.M.(2020) Progress and prospect of urban resilience research. Progress in Geography , 39(10): 1717-1731. https://doi.org/10.18306/dlkxjz.2020.10.011.

[5] Zhang W.Z.,Yu J.H.(2023).Policy evolution and transformation effect analysis of sustainable development of resource-based cities in China. Journal of Natural Resources, 2023,38(01):22-38. https://doi.org/10.31497/zrzyxb.20230102

[6] RIGHI A W, SAURIN T A, WACHS P.(2015) A systematic literature review of resilience engineering: Research areas and a research agenda proposal [J]. Reliability Engineering & System Safety, 141: 142-52.

[7] Martin, R. Shocking aspects of regional development: Towards an economic geography of resilience. In G. Clark, M. Gertler, M. P. Feldman, & D. Wjcik (Eds.), The New Oxford Handbook of Economic Geography (pp. 839–864). Oxford: Oxford University Press.

[8] GILL A M. Enhancing social interaction in new resource towns: Planing perspectives. Tijdschrift Voor Economische EnSociale Geografie, 1990, 81(5): 348-363.

[9] BRADBURY J H. The impact of industrial cycles in the mining sector: The case of the Québec-Labrador Region in Canada.International Journal of Urban and Regional Research, 1984, 8(3): 311-331.

[10] BRADBURY J H, ISABELLE S M. Winding down in a quebec mining town: A case study of Schefferville. The Canadian Geographer, 1983, 27(2): 128-144.

[11] UY T, YI K M, ZHANG J. (2013) Structural change in an open economy. Journal of Monetary Economics, 60(6): 667-682.

[12] KUAI P, LI W, CHENG R, et al. (2015) An application of system dynamics for evaluating planning alternatives to guide agreen industrial transformation in a resource-based city. Journal of Cleaner Production, 104: 403-412.

[13] LI H, WANG Y, ZHANG H, et al. (2024) The spatial-temporal evolution and driving mechanism of Urban resilience in the Yellow River Basin cities [J]. Journal of Cleaner Production, 447.