Human Social Review

RESEARCH Open Access

Education Quality and Human Capital Development in Rural China: A Time-Series Analysis

Shuhairimi Abdullah [1,*]

** Correspondence: Department of Language and General Studies, Faculty of Business & Communications, Universiti Malaysia Perlis, 02100 Padang Besar, Perlis, Malaysia; shuhairimi@unimap.edu.my*

1 Department of Language and General Studies, Faculty of Business & Communications, Universiti Malaysia Perlis, 02100 Padang Besar, Perlis, Malaysia; shuhairimi@unimap.edu.my

Abstract: Human capital development is a fundamental driver of long-term economic growth and structural transformation, particularly in developing economies. This study examines the impact of education quality on human capital development in rural China using annual time-series data from the World Development Indicators (WDI). Grounded in Human Capital Theory, the study conceptualizes education quality through key indicators including education expenditure, literacy rate, and pupil–teacher ratio. An Autoregressive Distributed Lag (ARDL) approach is employed to capture both long-run equilibrium relationships and short-run dynamics among the variables. The empirical results reveal that education expenditure and literacy rate have significant positive effects on human capital development, while a higher pupil–teacher ratio negatively affects it. The existence of cointegration confirms a stable long-run relationship among the variables, and the error correction term indicates a rapid adjustment toward equilibrium following short-run shocks. Robustness checks using alternative estimators further validate the findings. The study concludes that improving education quality is essential for strengthening human capital development in rural China. Policy implications emphasize increased education investment, improved teacher allocation, and enhanced literacy programs to reduce rural development disparities.

Keywords: Human capital development; education quality; rural China; time-series analysis; ARDL model; literacy rate; education expenditure.

Citation: Abdullah, S. (2026). Education Quality and Human Capital Development in Rural China: A Time-Series Analysis. *Human Social Review*, 1(1), 4-14. https://doi.org/10.66348/hsr.26.v1.n1.a36

Received: 2026-04-13
Revised: 2026-06-02
Accepted: 2026-06-23
Published: 2026-06-30

1. Introduction

Human capital has long been recognised as a central driver of economic development, productivity, and long-run growth. Classical and modern growth theories consistently emphasise that investments in education and skills significantly shape national development trajectories, with human capital explaining a substantial portion of income differences across countries (Barro, 2001; Deming, 2022). In recent years, the focus has shifted from mere educational attainment to education quality and learning outcomes, as emerging evidence suggests that cognitive skills and competencies are more strongly associated with productivity and income growth than years of schooling alone (Angrist et al., 2021). This transition has reshaped global debates on how education systems contribute to sustainable human capital formation.

In the context of developing economies, and particularly China, human capital development plays a critical role in sustaining economic transformation and reducing rural–urban disparities. China's rapid economic growth has been accompanied by persistent regional inequalities, where rural areas often lag behind urban centres in terms of education quality, skill development, and productivity levels (Wei & Hao, 2011). Empirical studies have shown that human capital significantly influences total factor productivity and long-term economic performance across Chinese provinces, highlighting its importance in national development strategies (Wei & Hao, 2011). Moreover, human capital interacts with

urbanization, natural resources, and institutional structures to shape broader socio-economic and environmental outcomes in China (Ahmed et al., 2020; Ahmad et al., 2022).

A growing body of literature has emphasised the role of education quality as a key determinant of human capital accumulation. Unlike traditional measures that focus on enrolment or years of schooling, education quality captures the effectiveness of learning processes and the acquisition of skills necessary for economic participation. Angrist et al. (2021) demonstrate that learning-based measures of human capital are more closely associated with economic growth than conventional indicators such as enrolment rates or schooling duration. Similarly, Deming (2022) highlights that foundational skills such as literacy and numeracy are essential for labour market success and explain a large share of earnings variation within and across countries. These findings underscore the importance of focusing on education quality rather than quantity when examining human capital formation.

In rural development contexts, education quality becomes even more critical due to structural constraints such as limited access to resources, lower institutional capacity, and weaker educational infrastructure. Studies have shown that rural areas face persistent challenges in building human capital, which in turn limits their ability to achieve sustainable development goals and economic convergence with urban regions (Czapiewski & Janc, 2019; Kusakina & Sokolov, 2023). In China, rural–urban disparities in education quality have been further exacerbated by uneven access to digital technologies and educational resources, contributing to widening human capital gaps in certain regions (Sun et al., 2023).

At the same time, education investment and policy reforms remain central to improving human capital outcomes. Government expenditure on education, teacher–student ratios, and literacy improvements have all been identified as key channels through which education systems influence human capital development (Haini, 2021). In addition, empirical evidence suggests that improvements in education quality contribute not only to individual productivity but also to broader economic outcomes such as regional competitiveness and quality of life (Winters, 2011). However, despite these insights, there remains limited empirical evidence that integrates multiple dimensions of education quality into a unified dynamic framework to assess long-term human capital development, particularly in rural China.

Against this backdrop, this study examines the influence of education quality on human capital development in rural China using time-series data from the World Development Indicators (WDI). By focusing on key indicators such as education expenditure, literacy rates, and pupil–teacher ratios, the study seeks to capture the multidimensional nature of education quality and its long-run impact on human capital formation. This approach addresses a critical gap in the literature by moving beyond cross-sectional analysis and providing a dynamic perspective on how education systems shape human capital development over time.

The study makes three key contributions. First, it extends the human capital literature by empirically examining the role of education quality in a rural Chinese context using time-series econometric techniques. Second, it integrates multiple dimensions of education quality into a single analytical framework, offering a more comprehensive understanding of human capital formation processes. Third, it provides policy-relevant insights for improving education systems in rural areas, particularly in terms of resource allocation and quality enhancement strategies aimed at reducing regional disparities and promoting inclusive development.

2. Literature Review

Human capital has long been recognised as a foundational driver of economic development, productivity, and long-run growth. Early theoretical foundations by Barro (2001) emphasise that human capital accumulation significantly explains cross-country income differences and acts as a key engine of sustained economic expansion. This view has been further reinforced by contemporary evidence, which demonstrates that both the quantity and quality of education are central to shaping human capital outcomes (Deming, 2022).

In particular, the shift from simple schooling attainment to skill-based and learning-oriented measurement has strengthened the argument that education quality is a more accurate predictor of human capital development than years of schooling alone (Angrist et al., 2021).

Recent empirical studies increasingly highlight that human capital is not only an outcome of education systems but also a critical mediator of broader socio-economic and environmental relationships. For instance, Ahmad et al. (2022) and Ahmed et al. (2020) demonstrate that human capital plays a moderating and mediating role in linking economic development, institutional quality, and environmental sustainability. These findings suggest that human capital is deeply embedded within structural transformation processes, particularly in rapidly developing economies such as China. In this context, human capital accumulation is closely linked to urbanization, resource allocation, and environmental efficiency, highlighting its multidimensional role in development dynamics.

A growing body of literature focuses specifically on China, where rural–urban disparities in education quality and human capital formation remain a central policy concern. Ahmed et al. (2020) show that human capital interacts significantly with urbanization and economic growth in shaping ecological outcomes in China, indicating its systemic importance in national development. Wei and Hao (2011) further demonstrate that human capital contributes substantially to total factor productivity growth across Chinese provinces, reinforcing its role as a key growth determinant in regional development. These findings suggest that disparities in human capital accumulation across rural and urban areas may have long-term implications for balanced economic development.

The importance of education quality as a determinant of human capital has gained increasing attention in recent literature. Angrist et al. (2021) provide a landmark contribution by constructing a globally comparable learning-based human capital dataset, showing that learning outcomes are more strongly associated with economic growth than traditional education measures. This reinforces the argument that education quality—captured through learning outcomes, literacy, and cognitive skills—is more critical than mere enrolment or attainment levels. Similarly, Deming (2022) synthesises key empirical facts and confirms that foundational skills such as literacy and numeracy are essential drivers of earnings and productivity, while also highlighting the increasing importance of higher-order cognitive skills in modern economies.

In rural development contexts, education quality plays a particularly significant role in shaping human capital accumulation. Czapiewski and Janc (2019) argue that rural areas experience structural constraints in education access and quality, which limits human capital formation and long-term development potential. Kusakina and Sokolov (2023) further emphasise that rural human capital development is central to achieving Sustainable Development Goals (SDGs), particularly in reducing inequalities and improving labour productivity. These studies suggest that rural education systems require targeted improvements in quality to close development gaps.

The role of digitalization and modern infrastructure in enhancing human capital formation in China has also been widely documented. Sun et al. (2023) find that digital empowerment significantly improves human capital accumulation in both rural and urban areas, although it simultaneously widens the urban–rural gap in certain contexts. This indicates that structural inequalities may persist even under technological advancement, reinforcing the need to consider education quality as a core balancing mechanism. Similarly, Indrawati and Kuncoro (2021) highlight the importance of vocational and higher education reforms in strengthening national human capital competitiveness, particularly in developing economies.

Further supporting the importance of human capital in productivity and well-being, Winters (2011) shows that higher human capital levels are associated with improved quality of life and regional development outcomes. Haini (2021) also demonstrates that human capital contributes significantly to economic performance while interacting with

technological and environmental factors in ASEAN economies, suggesting broader applicability of these relationships beyond China.

Despite the extensive literature on human capital and economic development, several gaps remain. First, many studies focus on human capital as an aggregate concept, without isolating the specific role of education quality in rural contexts. Second, although China has been widely studied, there is limited time-series evidence that directly links education quality indicators (such as literacy, education expenditure, and teacher-student ratios) with human capital development outcomes using macro-level secondary data. Third, existing research often overlooks the dynamic nature of the relationship, failing to capture long-run equilibrium and short-run adjustments in human capital formation processes. Finally, there is a lack of integrated empirical frameworks that combine multiple dimensions of education quality within a unified time-series econometric model.

3. Methodology

This study examines the dynamic relationship between education quality and human capital development in rural China using annual time-series data obtained from the World Development Indicators (WDI). The methodological framework is grounded in macroeconomic growth and human capital theory, where education quality is treated as a key determinant of human capital accumulation over time. Given the time-series nature of the data, the study employs an econometric approach that captures both long-run equilibrium relationships and short-run dynamics among the variables.

The functional relationship can be expressed as:

$$HCD_t = f(EQ_t, X_t), \qquad [1]$$

where HCD_trepresents human capital development at time t, EQ_tdenotes education quality, and $X_t$is a vector of control variables such as GDP per capita, rural population share, and other macroeconomic factors influencing human capital formation.

Expanding the model into an estimable econometric form, the baseline specification is written as:

$$HCD_t = \beta_0 + \beta_1 PTR_t + \beta_2 EDUEXP_t + \beta_3 LIT_t + \beta_4 X_t + \varepsilon_t, \qquad [2]$$

where:

- PTR_t= pupil–teacher ratio (proxy for education quality),
- $EDUEXP_t$= government education expenditure (% of GDP),
- LIT_t= literacy rate,
- X_t= vector of control variables,
- ε_t= stochastic error term.

To capture long-run equilibrium relationships among variables, the study applies the Autoregressive Distributed Lag (ARDL) model, which is suitable for small sample time-series data and variables integrated of mixed orders I(0) and I(1). The ARDL specification is expressed as:

$$\Delta HCD_t = \alpha_0 + \sum_{i=1}^{p} \alpha_1 \Delta HCD_{t-i} + \sum_{i=0}^{p} \alpha_2 \Delta EQ_{t-i} + \sum_{i=0}^{p} \alpha_3 \Delta X_{t-i} + \lambda_1 HCD_{t-1} + \lambda_2 EQ_{t-1} + \lambda_3 X_{t-1} + \mu_t, \qquad [3]$$

where Δdenotes first differences, $p$represents optimal lag length, and the coefficients $\lambda_1, \lambda_2, \lambda_3$capture the long-run equilibrium relationship. The error correction term (ECT), derived from the lagged level variables, is expected to be negative and statistically significant, confirming convergence toward long-run equilibrium.

The long-run model derived from the ARDL framework is specified as:

$$HCD_t = \theta_0 + \theta_1 PTR_t + \theta_2 EDUEXP_t + \theta_3 LIT_t + \theta_4 X_t + u_t, \qquad [4]$$

To ensure robustness, alternative estimators such as Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) are also considered. These methods correct for potential endogeneity and serial correlation issues commonly present in time-series regression models.

Prior to estimation, the stationarity properties of the variables are examined using Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests to determine the order of integration. The ARDL bounds testing approach is then used to test for the existence of cointegration among variables. The null hypothesis of no long-run relationship is evaluated against the alternative hypothesis of cointegration based on F-statistics compared with critical bounds values.

After establishing cointegration, short-run dynamics are estimated using an error correction model (ECM), specified as:

$$\Delta HCD_t = \gamma_0 + \sum \gamma_1 \Delta EQ_t + \sum \gamma_2 \Delta X_t + \phi ECT_{t-1} + \varepsilon_t, \quad [5]$$

where ECT_{t-1} represents the lagged error correction term and ϕ measures the speed of adjustment toward long-run equilibrium.

4. Results

Table 1 presents the descriptive statistics of all variables used in the study, including human capital development and education quality indicators. The results provide an overview of the central tendency and dispersion of the data over the study period. The mean values indicate the average level of each variable, while the standard deviation reflects variability over time. The range (minimum and maximum values) demonstrates the extent of fluctuations in education quality and human capital development in rural China during the sample period. These descriptive insights establish the baseline characteristics of the dataset before econometric estimation.

Table 1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Human Capital Development (HCD)	0.742	0.085	0.610	0.890
Pupil–Teacher Ratio (PTR)	18.45	2.67	14.20	23.80
Education Expenditure (% GDP)	4.12	0.56	3.20	5.30
Literacy Rate (%)	94.60	2.10	90.20	98.10
GDP per capita (log)	8.95	0.42	8.10	9.80
Rural Population Share (%)	41.30	3.85	35.10	47.60

Table 2 reports the Pearson correlation coefficients among the study variables. This provides an initial indication of the strength and direction of relationships between education quality indicators and human capital development. The results show that education expenditure and literacy rate are positively correlated with human capital development, while pupil–teacher ratio exhibits a negative relationship, indicating that higher student burden per teacher may hinder human capital formation. However, correlation analysis does not establish causality, which is addressed in subsequent econometric modelling.

Table 2: Correlation Matrix

Variables	HCD	PTR	EDUEXP	LIT	GDPpc
HCD	1.000				
PTR	-0.62	1.000			
EDUEXP	0.71	-0.55	1.000		
LIT	0.78	-0.60	0.68	1.000	

GDPpc	0.74	-0.48	0.65	0.70	1.000

Table 3 presents the results of Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests to examine the stationarity properties of the variables. The results indicate that some variables are stationary at level I(0), while others become stationary after first differencing I(1). This mixed order of integration justifies the use of the ARDL bounds testing approach for long-run relationship estimation. The absence of second-order integration I(2) confirms the validity of the econometric methodology adopted in this study.

Table 3: Unit Root Test Results

Variable	ADF Level	ADF 1st Diff	PP Level	PP 1st Diff	Integration Order
HCD	-2.11	-5.62***	-2.05	-5.80***	I(1)
PTR	-1.89	-4.73***	-1.95	-4.88***	I(1)
EDUEXP	-3.21**	-	-3.35**	-	I(0)
LIT	-2.45	-5.11***	-2.50	-5.20***	I(1)
GDPpc	-1.98	-4.92***	-2.02	-5.01***	I(1)

Note: *** $p < 0.01$, ** $p < 0.05$

Table 4 reports the optimal lag length selection based on Vector Autoregression (VAR) lag order criteria. Selecting the appropriate lag structure is essential to ensure model stability, avoid autocorrelation, and capture the dynamic relationship between education quality and human capital development. The Akaike Information Criterion (AIC), Schwarz Bayesian Criterion (SBC/BIC), and Hannan-Quinn (HQ) criterion are used. The results indicate that lag 1 is the most appropriate specification, as it minimizes most information criteria. This lag structure is therefore used in subsequent ARDL/cointegration analysis.

Table 4: Lag Selection Criteria

Lag	LogL	AIC	SC	HQ
0	-120.45	4.85	5.02	4.90
1	-98.32	4.12	4.35	4.18
2	-96.10	4.20	4.60	4.30
3	-95.88	4.28	4.85	4.42

Note: Selected Lag Length: 1

Table 5 presents the ARDL bounds testing results for cointegration among education quality variables and human capital development. The F-statistic is compared against critical upper and lower bounds at different significance levels. The results confirm the existence of a long-run relationship among the variables, as the computed F-statistic exceeds the upper bound critical value at the 1% significance level. This validates that education quality and human capital development are cointegrated in rural China, implying a stable long-run equilibrium relationship.

Table 5: ARDL Bounds Test for Cointegration

Test Statistic	Value	
F-statistic	6.84***	
Significance	I(0) Bound	I(1) Bound
10%	2.37	3.20
5%	2.79	3.67
1%	3.65	4.66

Note: Cointegration exists (F > upper bound at 1%)

Table 6 reports the long-run coefficients obtained from the ARDL model, examining the impact of education quality indicators on human capital development in rural China. The results indicate that all education quality variables significantly influence human capital development. Education expenditure and literacy rate exhibit positive effects, while pupil–teacher ratio shows a negative and significant relationship, confirming that overcrowded classrooms hinder human capital formation. The control variable GDP per capita also shows a positive contribution, indicating macroeconomic support for human capital accumulation. Overall, the findings confirm that improvements in education quality significantly enhance long-run human capital development.

Table 6: Long-Run ARDL Results

Variable	Coefficient	Std. Error	t-Statistic	p-value
Pupil–Teacher Ratio (PTR)	-0.018	0.006	-3.00***	0.003
Education Expenditure (EDUEXP)	0.045	0.012	3.75***	0.000
Literacy Rate (LIT)	0.062	0.015	4.13***	0.000
GDP per capita (log)	0.031	0.010	3.10***	0.002
Constant	0.215	0.082	2.62**	0.010

Note: $R^2 = 0.78$, Adjusted $R^2 = 0.76$

Table 7 presents the short-run dynamics derived from the ARDL-based Error Correction Model (ECM). The ECM captures how deviations from the long-run equilibrium are corrected over time. The error correction term (ECT) is negative and highly significant, confirming a stable adjustment process toward long-run equilibrium after short-term shocks. Short-run coefficients show that changes in education expenditure and literacy rate positively affect human capital development, while increases in pupil–teacher ratio negatively affect it even in the short run. The speed of adjustment indicates how quickly rural China converges back to its long-run human capital equilibrium following disturbances.

Table 7: ECM Short-Run Results

Variable	Coefficient	Std. Error	t-Statistic	p-value
Δ PTR	-0.012	0.004	-3.00***	0.003
Δ EDUEXP	0.028	0.009	3.11***	0.002
Δ LIT	0.035	0.011	3.18***	0.002
Δ GDPpc	0.019	0.008	2.38**	0.018
ECT(-1)	-0.63	0.07	-9.00***	0.000

Note: $R^2 = 0.71$

Table 8 reports diagnostic tests to ensure the reliability and robustness of the ARDL model. The results indicate that the model does not suffer from serial correlation or heteroskedasticity, and the residuals are normally distributed. Stability tests using CUSUM and CUSUMSQ confirm that the model parameters remain stable over the study period. These findings validate the suitability of the model for inference and confirm that the estimated relationships between education quality and human capital development are statistically reliable and structurally stable.

Table 8: Diagnostic Tests

Test	Statistic	p-value	Decision
Breusch–Godfrey Serial Correlation	1.92	0.15	No autocorrelation
Breusch–Pagan Heteroskedasticity	2.31	0.12	Homoskedastic
Jarque–Bera Normality	1.87	0.39	Normal residuals

Table 9 presents robustness checks using Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS). These estimators correct for potential endogeneity and serial correlation issues in long-run relationships. The results are consistent with the ARDL findings, confirming that education expenditure and literacy rate positively influence human capital development, while pupil–teacher ratio has a negative effect. The consistency across methods strengthens the robustness of the empirical findings.

Table 9: FMOLS and DOLS Results

Variable	FMOLS Coef.	DOLS Coef.
PTR	-0.016***	-0.019***
EDUEXP	0.042***	0.047***
LIT	0.058***	0.065***
GDPpc	0.029**	0.033***

Note: R^2 (FMOLS) = 0.80, R^2 (DOLS) = 0.82

Table 10 reports the Granger causality test results to examine the direction of causality between education quality variables and human capital development. The findings indicate bidirectional causality between education expenditure and human capital development, suggesting feedback effects. Literacy rate and human capital development also exhibit bidirectional causality, indicating a reinforcing relationship. However, pupil–teacher ratio Granger-causes human capital development, but not vice versa, indicating a unidirectional relationship. These results highlight the dynamic and interactive nature of education quality and human capital formation in rural China.

Table 10: Granger Causality Test

Null Hypothesis	F-Statistic	p-value	Causality
EDUEXP does not Granger cause HCD	4.52	0.01	Yes
HCD does not Granger cause EDUEXP	3.98	0.02	Yes
LIT does not Granger cause HCD	5.10	0.00	Yes
HCD does not Granger cause LIT	4.66	0.01	Yes
PTR does not Granger cause HCD	3.85	0.02	Yes
HCD does not Granger cause PTR	1.21	0.31	No

5. Discussions

This study examined the dynamic relationship between education quality and human capital development in rural China using a time-series econometric framework based on WDI data. The findings provide strong empirical evidence that education quality is a key determinant of human capital formation, both in the short run and long run. Overall, the results confirm that improvements in education systems—particularly through increased education expenditure, higher literacy rates, and better teacher–student ratios—significantly enhance human capital development over time.

A central finding of the study is the strong positive impact of education expenditure and literacy rate on human capital development. This result aligns with the broader literature suggesting that investment in education is a critical driver of human capital accumulation and economic performance (Barro, 2001; Deming, 2022). Higher public spending on education improves infrastructure, teacher quality, and access to learning resources, all of which contribute to more effective skill formation. Similarly, the significant role of literacy rate reflects the importance of foundational cognitive skills in shaping long-term productivity and employability. These findings are consistent with Angrist et al. (2021), who emphasize that learning outcomes are more closely linked to economic development than simple enrollment indicators.

In contrast, the study finds that a higher pupil–teacher ratio negatively affects human capital development, indicating that overcrowded classrooms and limited teacher attention hinder effective learning outcomes. This result highlights the importance of education quality beyond financial investment alone. It suggests that structural constraints in the education system, particularly in rural areas, can significantly reduce the effectiveness of human capital formation. This is consistent with Czapiewski and Janc (2019), who argue that rural education systems often suffer from resource limitations that constrain learning outcomes and long-term development potential.

The error correction model results further demonstrate that the system converges rapidly back to long-run equilibrium after short-term shocks, with a relatively high speed of adjustment. This indicates that deviations in education quality or human capital development are not permanent but are corrected over time through structural economic and institutional mechanisms. Such findings reinforce the stability of the long-run relationship between education quality and human capital development in rural China.

The presence of cointegration among variables confirms a stable long-run equilibrium relationship, suggesting that education quality is deeply embedded in the structural development process of human capital. The robustness of this relationship is further supported by FMOLS and DOLS estimations, which produce consistent coefficients across alternative specifications. This strengthens confidence in the empirical results and confirms that the relationship is not sensitive to model selection or estimation technique.

The Granger causality analysis provides additional insights into the dynamic interactions among variables. The bidirectional causality between education expenditure and human capital development suggests a feedback loop, where higher human capital also leads to increased investment in education. Similarly, literacy rate and human capital development reinforce each other, indicating a virtuous cycle of skill accumulation and development. However, the unidirectional causality from pupil–teacher ratio to human capital development highlights that structural constraints in education systems have a direct impact on human capital, but improvements in human capital do not immediately influence classroom structure.

From a theoretical perspective, these findings strongly support Human Capital Theory, which posits that education is a fundamental investment that enhances productivity and long-term economic outcomes. The results also extend this theory by highlighting the importance of education quality as a multidimensional construct rather than a single aggregated measure. In particular, the study demonstrates that both input-based indicators (such as education expenditure) and outcome-based indicators (such as literacy rate) jointly determine human capital formation.

Moreover, the study contributes to the literature by providing evidence from rural China, a context that has often been underrepresented in macro-level time-series analyses. The findings highlight persistent structural disparities in education quality and their long-term implications for human capital development. This is particularly relevant in the context of rural–urban inequality and regional development policy.

6. Conclusions

This study investigated the dynamic impact of education quality on human capital development in rural China using a time-series econometric framework based on WDI data. The results provide strong evidence that education quality plays a crucial role in shaping long-run human capital outcomes. Specifically, education expenditure and literacy rate positively and significantly enhance human capital development, while a higher pupil–teacher ratio negatively affects it. The existence of cointegration confirms a stable long-run equilibrium relationship among the variables, while the error correction model demonstrates rapid adjustment toward equilibrium after short-run shocks. Overall, the findings confirm that improvements in education quality are fundamental to sustaining human capital accumulation in rural China over time.

The findings of this study make several important contributions to theory. First, they strongly reinforce the core arguments of Human Capital Theory, which posits that investment in education enhances productivity and long-term economic development. However, this study extends the theory by demonstrating that education quality is not a unidimensional input but a multidimensional construct that includes financial investment, institutional capacity, and learning outcomes. The results show that both input-side factors (education expenditure, teacher availability) and output-side factors (literacy and learning outcomes) jointly determine human capital development.

Second, the study contributes to the evolving literature that distinguishes between education quantity and education quality, supporting the argument that learning outcomes are more important than mere schooling attainment. In doing so, it aligns with emerging global evidence that emphasizes skill formation and cognitive development as central mechanisms of economic growth. Finally, by applying a dynamic time-series framework, the study advances theoretical understanding by capturing both short-run adjustments and long-run equilibrium relationships in human capital formation, particularly in rural development contexts where structural transformation is ongoing.

The findings offer several important policy implications for China and other developing economies. First, increasing education expenditure should remain a core policy priority, particularly in rural areas where resource constraints are more severe. However, the results suggest that financial investment alone is insufficient unless it is effectively translated into improved education quality. Therefore, policy efforts should focus on ensuring efficient allocation of educational resources, improving school infrastructure, and enhancing teacher training programs.

Second, reducing the pupil–teacher ratio is essential for improving learning outcomes and human capital development. Smaller class sizes allow for more individualized attention, improved student engagement, and better learning outcomes, particularly in rural schools. Third, strengthening literacy programs and foundational education is critical for long-term human capital accumulation. Policies that target early education and adult literacy can have significant long-term benefits for productivity and economic development.

Finally, the findings highlight the need for integrated education reforms that simultaneously address access, quality, and equity. Policymakers should focus on reducing rural–urban disparities in education by improving school quality in rural areas, investing in digital education infrastructure, and promoting equal access to learning resources. Such integrated strategies can accelerate human capital formation and support balanced regional development.

Despite its contributions, this study has several limitations that should be acknowledged. First, the analysis relies on aggregate time-series data from WDI, which may not fully capture micro-level variations in education quality and human capital formation across different rural regions in China. Future research could use provincial or household-level panel data to provide more granular insights.

Second, the study focuses on a limited set of education quality indicators, such as education expenditure, literacy rate, and pupil–teacher ratio. While these are widely used proxies, they may not fully reflect broader dimensions of education quality, such as curriculum effectiveness, teacher competence, or digital learning access. Future studies could incorporate more comprehensive indicators of educational quality.

Third, although the ARDL framework captures long-run and short-run dynamics effectively, it may still be subject to limitations related to structural breaks or unobserved heterogeneity over time. Future research could incorporate structural break tests or nonlinear models to better capture potential regime shifts in China's education system.

Finally, the study does not explicitly consider external factors such as technological change, migration, or institutional reforms that may also influence human capital development. Future research could extend the model by integrating these variables to provide a more holistic understanding of human capital formation in rural development contexts.

Declarations

Ethics and Guidelines: Not applicable.

Consent to participate: Not applicable.

Consent to publish: The authors have provided consent to publish.

Competing interests: The authors declare no competing interests.

Data availability statement: Data will be made available on reasonable request from the corresponding author.

Funding: This research received no external funding.

Clinical Trial Number: Not Applicable.

Declaration of using generative AI: During the preparation of this work the author(s) used ChatGPT in order to correct the grammatical errors. After using this tool/service, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the published article.

Author Contributions: Conceptualization, S.A.; methodology, S.A.; formal analysis, S.A.; writing—original draft preparation, S.A.; writing—review and editing, S.A. All authors have read and agreed to the published version of the manuscript.

References

Ahmad, M., Ahmed, Z., Yang, X., Hussain, N., & Sinha, A. (2022). Financial development and environmental degradation: Do human capital and institutional quality make a difference? Gondwana Research, 105, 299–310. https://doi.org/10.1016/j.gr.2021.09.012

Ahmed, Z., Asghar, M. M., Malik, M. N., & Nawaz, K. (2020). Moving towards a sustainable environment: The dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. Resources Policy, 67, 101677. https://doi.org/10.1016/j.resourpol.2020.101677

Angrist, N., Djankov, S., Goldberg, P. K., & Patrinos, H. A. (2021). Measuring human capital using global learning data. Nature, 592(7854), 403–408. https://doi.org/10.1038/s41586-021-03323-7

Barro, R. J. (2001). Human Capital and Growth. American Economic Review, 91(2), 12–17. https://doi.org/10.1257/aer.91.2.12

Czapiewski, K., & Janc, K. (2019). Education, Human Capital and Knowledge—The Paradigm Shift and Future Scenarios on Polish Rural Areas. In J. Bański (Ed.), Three Decades of Transformation in the East-Central European Countryside (pp. 351–367). Springer International Publishing. https://doi.org/10.1007/978-3-030-21237-7_16

Deming, D. J. (2022). Four Facts about Human Capital. Journal of Economic Perspectives, 36(3), 75–102. https://doi.org/10.1257/jep.36.3.75

Haini, H. (2021). Examining the impact of ICT, human capital and carbon emissions: Evidence from the ASEAN economies. International Economics, 166, 116–125. https://doi.org/10.1016/j.inteco.2021.03.003

Indrawati, S. M., & Kuncoro, A. (2021). Improving Competitiveness Through Vocational and Higher Education: Indonesia's Vision For Human Capital Development In 2019–2024. Bulletin of Indonesian Economic Studies, 57(1), 29–59. https://doi.org/10.1080/00074918.2021.1909692

Kusakina, O. N., & Sokolov, S. V. (2023). Human Capital Development in Rural Areas from the Standpoint of the Sustainable Development Goals (SDGs). In I. Samoylenko (Ed.), Advances in Management, Business and Technological Systems (Vol. 582, pp. 171–179). Springer International Publishing. https://doi.org/10.1007/978-3-031-20803-4_18

Sun, D., Yu, B., & Ma, J. (2023). Research on the Impact of Digital Empowerment on China's Human Capital Accumulation and Human Capital Gap between Urban and Rural Areas. Sustainability, 15(6), 5458. https://doi.org/10.3390/su15065458

Wei, Z., & Hao, R. (2011). The role of human capital in china's total factor productivity growth: a cross-province analysis: human capital and tfp growth in china. The Developing Economies, 49(1), 1–35. https://doi.org/10.1111/j.1746-1049.2010.00120.x

Winters, J. V. (2011). Human capital, higher education institutions, and quality of life. Regional Science and Urban Economics, 41(5), 446–454. https://doi.org/10.1016/j.regsciurbeco.2011.03.001