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Effects of Carbon Dioxide Emissions on Child Mortality in Nepal

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ABSTRACT

The rising levels of carbon dioxide (CO_2) emissions have intensified concerns about public health impacts, especially in developing countries where economic growth often increases environmental strain. This study aims to examine the relationship between CO_2 emissions and child mortality in Nepal, incorporating factors such as economic growth, health expenditure, and educational attainment. Using time-series data from 2001 to 2021, Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegrating Regression (CCR) models were employed to assess the long-term relationships between these variables. Results indicate that a 1% increase in CO_2 emissions is associated with an approximate 0.11% rise in child mortality, underscoring the detrimental effects of environmental degradation. Additionally, economic growth and health expenditure were found to significantly lower child mortality, with a 1% increase in GDP per capita reducing child mortality by 0.69% and a similar increase in health expenditure decreasing it by 0.22%. Higher educational attainment also significantly decreased child mortality rates by 0.19%. These findings suggest that policies addressing both environmental and socioeconomic factors are essential to improving child health outcomes. Overall, the study highlights the importance of integrated policy approaches in mitigating child mortality through environmental protection, economic development, and social investment.

Keywords: CO_2 Emissions, Child Mortality, Economic Growth, Environmental Impact, Health Outcomes, Sustainability
JEL Classifications: I15, Q53, O15, I21

1. INTRODUCTION

The escalating impact of environmental degradation on public health has raised significant scientific concerns, particularly in developing countries, where vulnerable populations face the dual challenges of poverty and pollution (Adeleye et al., 2022; Barua et al., 2022). The relationship between carbon dioxide (CO_2) emissions and health outcomes, including child mortality, has become increasingly relevant due to its implications for sustainable development and public health goals (Sinha, 2014; Guo et al., 2024). CO_2 emissions, primarily from fossil fuel consumption, exacerbate air pollution and climate change, which have been shown to contribute to poor health outcomes in children by increasing their exposure to respiratory illnesses and other adverse conditions (Oyedele, 2022; Sial et al., 2022).

This research addresses a critical scientific problem: Understanding how environmental factors, specifically CO_2 emissions, impact child mortality rates in Nepal, a context where rapid urbanization and economic growth present unique health and environmental risks (Paudel, 2024). Although studies have examined this relationship in other regions, such as South Asia and Sub-Saharan Africa, limited research exists on its effects within Nepal (Nwani and Ujah, 2024). Investigating these connections within the Nepalese context not only adds to the global understanding of the environmental determinants of health but also informs local strategies to balance economic development with public health priorities.

2. LITERATURE REVIEW

Child mortality remains a significant public health concern globally, particularly in developing regions. A multitude of factors influences child health outcomes, including environmental, economic, and social variables. This literature review examines the nexus between child mortality rates and key determinants such as carbon emissions, health expenditure, educational attainment, access to safe drinking water and GDP Per capita.

2.1. Carbon Emissions and Child Mortality

Recent studies have highlighted the adverse effects of carbon emissions on health outcomes, including child mortality. Adeleye et al. (2022) explored the relationship between mortality rates, carbon emissions, and income in Sub-Saharan Africa, finding a direct correlation between higher carbon emissions and increased mortality rates among children. Similarly, Sinha (2014) conducted a causal analysis in India, revealing that rising carbon emissions negatively impacted child health. The findings of Guo et al. (2024) further reinforce this notion, indicating that CO_2 emissions, coupled with urbanization, adversely affect life expectancy and infant mortality in SAARC countries.

The mediating role of carbon emissions in the relationship between energy consumption and child mortality has also been emphasized. Adeleye et al. (2023) demonstrated that in the Asia-Pacific region, infant mortality is significantly affected by nonrenewable energy consumption through its impact on carbon emissions. Husnain et al. (2016) and Nwani and Ujah (2024) extended this discussion by addressing the Sustainable Development Goal (SDG) 3 targets, underscoring the critical role of environmental factors, including carbon emissions, in achieving child mortality reduction goals in South Asia and Sub-Saharan Africa.

2.2. Health Expenditure

Health expenditure is another vital determinant of child mortality. Rana et al. (2018) conducted a comparative global analysis, illustrating that increased health expenditure correlates with decreased child and maternal mortality rates. Similarly, Paudel (2024) focused on Nepal, demonstrating a direct link between per capita health expenditure and improved child health outcomes. This relationship is further supported by findings from Houeninvo (2022), who analyzed health expenditures across 37 African countries and found a significant reduction in infant and child mortality rates with increased health funding. Moreover, Akter et al. (2023) revealed that health expenditure, alongside education and industrialization, significantly impacts child mortality rates in G-7 countries, suggesting that increased investment in health can yield substantial benefits for child health. Additionally, Adeosun and Faboya (2020) demonstrated that higher healthcare expenditure in Nigeria is significantly linked to lower child mortality rates, highlighting the importance of increased investment in health services to improve child health outcomes. Bhalotra (2007) found that increased state health expenditure in India is associated with a significant reduction in infant mortality rates, suggesting that investment in healthcare can lead to improved child health outcomes. Kiross et al. (2020) similarly demonstrated that increased health expenditure significantly reduces infant mortality rates in sub-Saharan Africa, underscoring the critical role of health investment in enhancing child health outcomes in the region. Furthermore, Nyamuranga and Shin (2019) identified a significant inverse relationship between public health expenditure and child mortality rates in Southern Africa, reinforcing the idea that increased investment in health services leads to improved child health outcomes. Rahman et al. (2018) also found that increased healthcare expenditure positively correlates with improved health outcomes across the SAARC-ASEAN region, further highlighting the critical role of investment in healthcare systems for enhancing population health. Finally, Shetty and Shetty (2014) established a positive correlation between health spending and reduced infant mortality rates in Asian countries, suggesting that increased financial investment in healthcare significantly contributes to better child health outcomes.

2.3. Educational Attainment

Educational attainment, particularly among parents, is crucial in understanding child mortality dynamics. Gakidou et al. (2010) provided a systematic analysis indicating that increased educational levels are associated with lower child mortality across 175 countries. This is echoed by Green and Hamilton (2019), who noted that maternal education significantly affects infant mortality rates in the United States. Furthermore, Balaj et al. (2021) conducted a global review showing that parental education is linked to inequalities in child mortality, emphasizing the importance of educational initiatives in health outcomes. In exploring these links further, Soares (2005) examined the causal connections between mortality reductions, educational attainment, and fertility choices, arguing that higher education leads to better health choices and lower mortality rates. This assertion is supported by the systematic review of Mensch et al. (2019), which demonstrated that education directly impacts maternal and child health outcomes. Additionally, Fuchs et al. (2010) found that education plays a more significant role than wealth in reducing child mortality rates in developing countries, highlighting the critical need for targeted educational interventions to improve child health outcomes.

2.4. Access to Safe Drinking Water

Access to safe drinking water and sanitation is crucial for reducing child mortality rates. Ly et al. (2022) revisited the impact of clean water and sanitation, identifying significant correlations between improved water access and decreased child mortality. Supporting this, Sharma Waddington et al. (2023) conducted a systematic review and meta-analysis, confirming that interventions aimed at enhancing water, sanitation, and hygiene (WASH) effectively lower childhood mortality rates. Additionally, Kremer et al. (2023) emphasized the critical role of water treatment in reducing child mortality, highlighting that effective interventions can lead to substantial health benefits.

Al Wazni et al. (2023) explored the intersection of climate change, water access, and child mortality, revealing that inadequate access to clean water exacerbates health issues, particularly diarrheal diseases, which significantly contribute to child mortality. Bulgamaa (2024) concluded that inequalities in water access substantially impact child mortality in low- and middle-income countries, underscoring the urgent need for equitable water distribution to enhance child health outcomes. Furthermore, Mebrahtom et al. (2022) found that inadequate water, sanitation, and hygiene conditions notably increased the risk of diarrhea-related infant mortality in eastern Ethiopia, reinforcing the critical need for improved public health interventions in these areas.

2.5. GDP Per Capita

Economic factors, particularly GDP per capita, play a crucial role in determining child health outcomes. Maruthappu et al. (2017) found that economic downturns have a negative impact on child mortality rates globally, with recessions particularly increasing child mortality in low- and middle-income countries. Complementing this, O'Hare et al. (2013) conducted a systematic review and meta-analysis that revealed a significant negative relationship between income levels and child mortality rates in developing countries, demonstrating that higher income is associated with lower child mortality. Furthermore, Testoni Costa-Nobre et al. (2021) identified clusters of cause-specific neonatal mortality and established a significant association between these clusters and per capita gross domestic product, suggesting that higher economic levels are linked to improved neonatal health outcomes. In addition to these findings, Trondillo (2016) highlighted that improvements in maternal and child health outcomes significantly contribute to increases in GDP per capita, underlining the economic benefits of investing in health initiatives. Finally, Shrestha and Jung (2023) found that healthcare reform initiatives in rural Nepal led to significant reductions in gender-specific infant mortality rates, emphasizing the importance of targeted health policies in enhancing child health outcomes.

The literature indicates that child mortality is influenced by a complex interplay of environmental, economic, and social factors. Carbon emissions, health expenditure, educational attainment, and access to safe drinking water collectively shape child health outcomes. Addressing these interconnected determinants is crucial for improving child mortality rates, particularly in vulnerable populations across developing regions. The hypotheses for this study are as follows:
H1: Increased CO_2 emissions will positively correlate with higher child mortality rates in Nepal.
H2: Economic growth will inversely correlate with child mortality, suggesting that higher GDP per capita may reduce mortality rates.
H3: Greater health expenditure will be associated with lower child mortality rates, indicating the protective role of healthcare investments.
H4: Higher levels of educational attainment will inversely correlate with child mortality, reflecting the role of education in improving health outcomes.

3. METHODOLOGY

3.1. Data Source and Variables

This study employs annual data from 2001 to 2021 obtained from the World Bank (see in Appendix 1). The variables include Child mortality rate, Carbon dioxide emissions per capita, health expenditure per capita, GDP per capita, educational attainment, and access to safe drinking water. Each variable's natural logarithm (LN) has been calculated to stabilize variance and linearize relationships for regression analysis (see Appendix 2). The variables and units were presented in Table 1.

3.2. Unit Root Testing

To ensure the stationarity of the time series data, the study employed the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. These tests were applied to all variables at both levels and first differences, under the assumptions of constant and trend. Stationarity of the variables is a necessary precondition for cointegration analysis (Poudel et al., 2024).

3.3. Johansen's Cointegration Test

Cointegration among variables is tested using the Johansen cointegration test, ensuring that the variables exhibit a long-term equilibrium relationship, justifying the use of FMOLS and CCR.

3.4. Model Specification

The Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegrating Regression (CCR) methods are utilized in this analysis to estimate the long-term relationship between child mortality (LNCMR) and its determinants, which include health expenditure (LNHE), GDP per capita (LNGDP), educational attainment (LNEA), access to safe water (LNSW), and CO_2 emissions ($LNCO_2$). These estimators are particularly suitable for handling issues of endogeneity and serial correlation in the presence of cointegration among variables.

The general form of the FMOLS and CCR regression models for this analysis is specified as follows:

$$LNCMR_t = \alpha+\beta_1\, LNCO_{2t} + \beta_2\, LNGDP_t + \beta_3\, LNEA_t + \beta_4\, LNSW_t + \beta_5\, LNHE_t + \epsilon_t$$

Where:
LNCMRt: Natural logarithm of the child mortality rate at time t,
α: Constant term,
β_1, β_2, β_3, β_4, and β_5: Long-run coefficients representing the elasticity of child mortality with respect to each independent variable,

Table 1: Description of variables and measurement

Variables	Definition	Measurement
CHR	Mortality rate, under-5	per 1,000 live births
CO_2	Carbon dioxide (CO_2) emissions excluding LULUCF per capita	Metric tons per capita per year
HE	Health expenditure per capita	USD
GDP	Gross domestic product per capita	constant 2015 USD
EA	Educational attainment, at least completed primary, population 25+years	Total (%) (cumulative)
SW	Access to safely managed drinking water services	% of the population

$LNCO_2t$: Natural logarithm of CO_2 emissions at time t,
LNGDPt: Natural logarithm of GDP per capita at time t,
LNEAt: Natural logarithm of educational attainment at time t,
LNSWt: Natural logarithm of access to safe water at time t,
LNHEt: Natural logarithm of health expenditure per capita at time t,
ϵt: Error term, capturing the unobserved factors affecting LNCMR at time t.

Both the FMOLS and CCR methods adjust for potential endogeneity among the regressors and correct for serial correlation, providing robust estimates of the long-run coefficients. This model specification allows us to examine the individual and combined effects of health expenditure, economic growth, education, safe water access, and environmental factors on child mortality.

3.5. Hansen Parameter Instability Test

To assess the stability of the long-run relationships among the variables, we employ the Hansen Parameter Instability Test. This test is specifically designed to detect any parameter instability within cointegrated relationships over time, making it ideal for assessing the robustness of our model in the presence of potential structural breaks or shifts. By applying this test, we can determine if the parameters of the cointegrating equation remain stable or if they exhibit significant changes due to factors like economic shocks, policy adjustments, or other external influences over the sample period (Poudel et al., 2024).

The Hansen test involves estimating a cointegrating vector and then examining whether this vector is stable across the sample period. The procedure utilizes the residuals from the cointegrating regression, testing for any systematic deviation that would indicate instability. For this purpose, we use the following hypotheses:

Null Hypothesis (H□): The parameters in the cointegrating relationship are stable over time.

Alternative Hypothesis (H□): There is instability in the parameters of the cointegrating relationship.

3.6. Wald Test

The Wald Test is a statistical test used to assess the significance of individual or joint restrictions on model parameters. It evaluates whether the coefficients in a regression model differ significantly from zero (or another specified value), based on the estimated parameter variances. A high Wald test statistic, relative to the critical value, leads to the rejection of the null hypothesis, indicating that the restrictions are invalid.

3.7. Granger Causality Tests

The Granger Causality Test examines whether one time series can predict another, helping determine the directional relationship between variables. If changes in one variable systematically occur before changes in another, it is said to "Granger-cause" the latter. A significant result suggests predictive causality, though not necessarily true causation (Kharel et al., 2024).

3.8. Normality Test

The Jarque-Bera test was used to check whether the residuals from the estimated models followed a normal distribution. The results indicated that the model residuals were normally distributed, confirming the reliability of the regression estimates (Khatri et al., 2024).

3.9. Software and Tools

The statistical analyses, including stationarity tests, cointegration tests, and FMOLS and CCR estimation, are conducted using statistical software Eviews 12, which provide robust implementations of the FMOLS and CCR method and related diagnostics.

4. RESULTS

4.1. Descriptive Statistics

Log-transforming variables in econometric analysis stabilizes variance, making relationships between variables linear and easier to interpret. This approach also normalizes data, reduces skewness, and allows for interpretation of coefficients as elasticities or percentage changes, enhancing economic insights. Table 1 provides descriptive statistics for essential health and economic indicators.

Table 2 exhibits variability that underscores both progress and persistent challenges in Nepal. The child mortality rate (LNCMR) and CO_2 emissions ($LNCO_2$) demonstrate considerable dispersion, reflecting economic activities' adverse effects on health. The mean GDP per capita (LNGDP) suggests moderate economic growth, though its range highlights disparities likely affecting health outcomes. Educational attainment (LNEA) and access to safe water (LNSW) show incremental improvements, yet their lower minimum values indicate persistent gaps. Health expenditure per capita (LNHE) also varies widely, with a positive skew, suggesting that while some regions allocate higher resources to health, many remain underfunded. These statistics collectively illustrate the intersection of economic growth with environmental and health challenges, advocating for targeted policies to bridge disparities in health and environmental quality.

4.2. Covariance Analysis of Variables

Understanding the interrelationship between variables through covariance analysis provides insights into how changes in one economic indicator may align with others. Table 2 shows the covariance and correlation coefficients among key health, environment and economic variables, offering a foundation for evaluating the strength and direction of these relationships.

Table 3 highlights significant interdependencies in Nepal's health, environmental, and economic domains. A notably strong negative correlation exists between child mortality rate (LNCMR) and CO_2 emissions ($LNCO_2$), GDP per capita (LNGDP), educational attainment (LNEA), and health expenditure (LNHE), indicating that higher economic and educational indicators are associated with lower child mortality. However, CO_2 emissions show a high positive correlation with LNGDP, suggesting that economic growth is heavily dependent on activities that increase emissions,

Table 2: Summary statistics of health, environment and economic indicators

Statistics	LNCMR	$LNCO_2$	LNEA	LNGDP	LNSW	LNHE
Mean	3.823600	−1.536804	3.670392	6.628437	3.237985	3.291643
Median	3.828641	−1.626617	3.676396	6.617420	3.316385	3.526361
Maximum	4.309456	−0.623562	3.936205	6.967425	3.396609	4.174387
Minimum	3.349904	−2.280063	3.431727	6.321430	2.777384	2.302585
Std. Dev.	0.293224	0.600445	0.132745	0.220361	0.180653	0.637076
Skewness	0.002111	0.342870	0.067592	0.108828	−1.355633	−0.267379
Kurtosis	1.841383	1.635966	2.455244	1.647981	3.601407	1.576894
Observations	21	21	21	21	21	21

Table 3: Covariance and correlation coefficients among key variables

Correlation	LNCMR	$LNCO_2$	LNEA	LNGDP	LNSW	LNHE
LNCMR	1.000000					
$LNCO_2$	−0.926687	1.000000				
	0.0000	-----				
LNEA	−0.917052	0.838340	1.000000			
	0.0000	0.0000	-----			
LNGDP	−0.991746	0.951539	0.908287	1.000000		
	0.0000	0.0000	0.0000	-----		
LNSW	0.752354	−0.819904	−0.624618	−0.759278	1.000000	
	0.0001	0.0000	0.0025	0.0001	-----	
LNHE	−0.980760	0.906279	0.902136	0.976801	−0.645952	1.000000
	0.0000	0.0000	0.0000	0.0000	0.0016	-----

potentially offsetting gains in health outcomes. Access to safe water (LNSW) correlates positively with LNCMR, possibly due to disparities in water access quality and availability. These correlations underline the economic-environmental trade-offs faced in Nepal and the importance of balancing economic growth with investments in education, healthcare, and environmental sustainability to ensure broader health and social benefits.

4.3. Trends in Health, Environment and Economic Indicators

Visualizing trends in health and economic indicators over time is essential for understanding their evolving impacts on population well-being and economic outcomes. Figure 1 illustrates the trends in key health, environment and economic indicators, offering a longitudinal perspective on these variables.

Figure 1 depicts trends in health, environment and economic indicators, illustrating how shifts in economic development correlate with health outcomes over time. The gradual decline in the child mortality rate (LNCMR) aligns with steady increases in GDP per capita (LNGDP), health expenditure per capita (LNHE), and educational attainment (LNEA), suggesting that economic growth and social investments have contributed to improved child health outcomes. However, CO_2 emissions per capita ($LNCO_2$) also rise alongside GDP, highlighting a potential environmental cost of economic expansion. This trend emphasizes the dual challenge Nepal faces: Fostering economic growth and social improvements while addressing environmental sustainability. The figure underscores the importance of implementing policies that mitigate pollution without compromising the economic gains essential for improving public health.

4.4. Unit Root Test Results

Testing for unit roots in time series data is a fundamental step in econometric analysis, ensuring that variables are stationary and suitable for regression without spurious results. Table 3 presents the results of the unit root tests for health, environment and economic indicators at level and first difference.

Table 4 provides the results of unit root tests (ADF and PP) applied to Nepal's health, environmental, and economic indicators, confirming whether the variables are stationary—a prerequisite for reliable regression analysis. The tests indicate that most variables, such as child mortality rate (LNCMR), CO_2 emissions per capita ($LNCO_2$), educational attainment (LNEA), GDP per capita (LNGDP), and health expenditure (LNHE), are non-stationary at levels but become stationary after first differencing, signifying integration of order one. This stationarity is critical for valid long-term modeling, as non-stationary variables could otherwise yield spurious correlations. The tests' findings justify using cointegration analysis to explore stable, long-run relationships between economic, environmental, and health factors in Nepal, which is essential for formulating effective, sustainable policy interventions.

Table 5 details the KPSS unit root test results, evaluating the stationarity of health, environmental, and economic indicators under the null hypothesis of stationarity. The KPSS test reveals that most variables, including child mortality rate (LNCMR), CO_2 emissions ($LNCO_2$), educational attainment (LNEA), GDP per capita (LNGDP), access to safe water (LNSW), and health expenditure (LNHE), exhibit non-stationarity at level in the presence of constant but attain stationarity upon differencing, consistent with integration of order one. These findings confirm the need to use differenced or cointegrated models in subsequent analysis, as failing to account for non-stationarity could distort regression results. Consequently, the KPSS test results substantiate the approach of modeling these variables in a cointegrated framework, thereby allowing for meaningful, long-run insights

Figure 1: Trends in health, environment and economic indicators

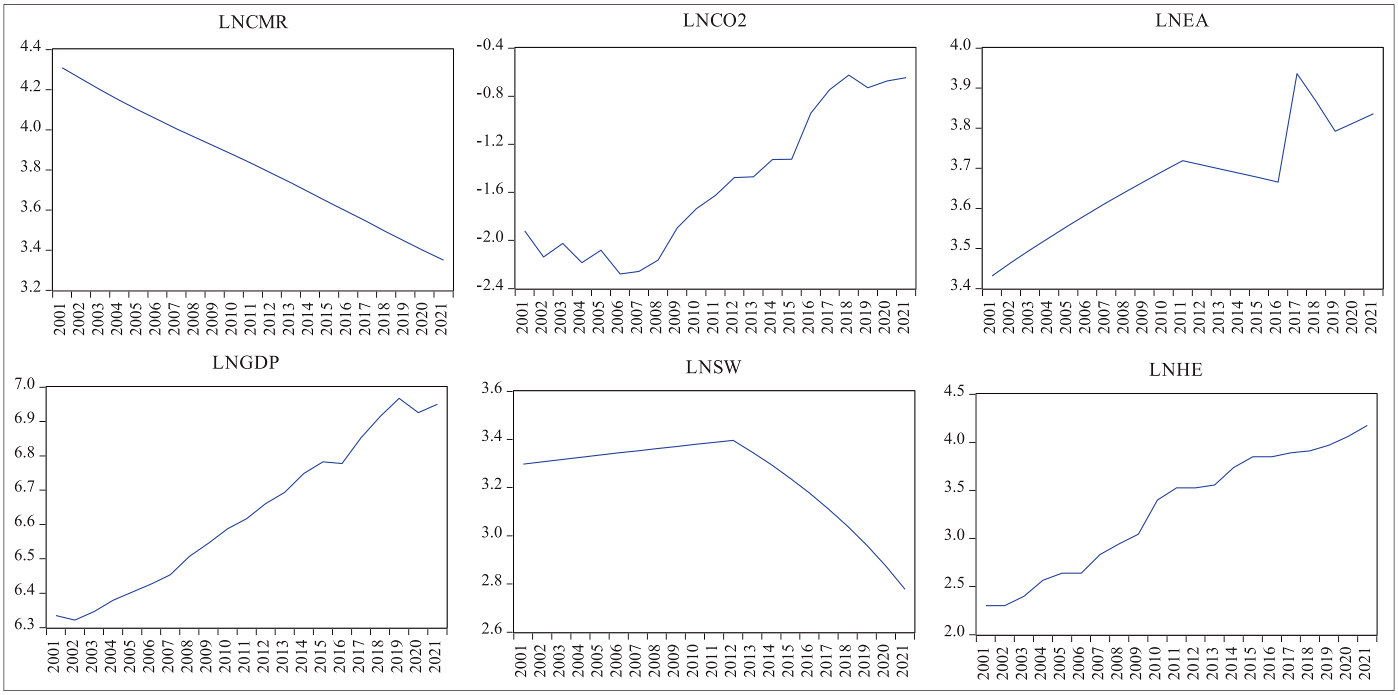


Table 4: Unit root test results for health, environment and economic indicators

			Unit root test table (PP)				
At level	**Statistic**	**LNCMR**	**LNCO$_2$**	**LNEA**	**LNGDP**	**LNSW**	**LNHE**
With Const.	t-statistic	−1.0180	0.1722	−1.4907	0.2299	2.8548	−0.7847
With C. and T.	t-statistic	−2.8262	−2.9284	−3.1498	−3.6299*	1.6294	−1.4730
First Diff.		**d (LNCMR)**	**d (LNCO$_2$)**	**d (LNEA)**	**d (LNGDP)**	**d (LNSW)**	**d (LNHE)**
With Const.	t-statistic	−2.4026	−4.4748***	−9.2025***	−5.0809***	0.2449	−3.9293***
With C. and T.	t-statistic	−2.1759	−4.4123**	−10.8759***	−4.7676***	−1.9893	−5.7870***
			Unit root test table (ADF)				
At level	**Statistic**	**LNCMR**	**LNCO$_2$**	**LNEA**	**LNGDP**	**LNSW**	**LNHE**
With Const.	t-statistic	−0.2207	0.3181	−1.5844	1.0376	−0.1968	−0.7415
With C. and T.	t-statistic	−5.6900***	−3.3267*	−3.2894*	−3.8314**	0.0101	−1.4086
First Diff.		**d (LNCMR)**	**d (LNCO$_2$)**	**d (LNEA)**	**d (LNGDP)**	**d (LNSW)**	**d (LNHE)**
With Const.	t-statistic	−3.0605*	−2.9464****	−5.0870***	−3.2420**	0.2008	−3.9267***
With C. and T.	t-statistic	−2.0301	−4.4188**	−10.9022***	−2.0626	−1.9945	−4.1328**

Table 5: Unit root test results table (KPSS)

			Null hypothesis: The variable is stationary				
At level	**Statistic**	**LNCMR**	**LNCO$_2$**	**LNEA**	**LNGDP**	**LNSW**	**LNHE**
With constant	t-statistic	0.6412**	0.5694**	0.6035**	0.6242**	0.4504*	0.6224**
With C. and T.	t-statistic	0.0961	0.1368*	0.0776	0.1567**	0.1731**	0.1560**
At first difference	**Statistic**	**d (LNCMR)**	**d (LNCO$_2$)**	**d (LNEA)**	**d (LNGDP)**	**d (LNSW)**	**d (LNHE)**
With constant	t-statistic	0.2052	0.2630	0.5000**	0.1847	0.5499**	0.1551
With C. and T.	t-statistic	0.1295*	0.1242*	0.5000***	0.1657**	0.1516**	0.1321*

into the interactions between economic growth, environmental factors, and health outcomes in Nepal.

Table 6 presents the lag length criteria for the Vector Autoregressive (VAR) model, aimed at effectively capturing the dynamics between Nepal's health, environmental, and economic indicators. Key criteria—Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan-Quinn (HQ)—all indicate that a lag length of 1 is optimal. This choice strikes a balance between capturing short-term relationships without adding complexity or multicollinearity, ensuring model accuracy and interpretability. The single-lag structure allows recent past values to inform predictions, supporting a clear analysis of short-term policy impacts on health expenditure, GDP per capita, and other indicators. Consequently, this one-lag setup provides a robust foundation for examining the intertemporal relationships among key variables in Nepal's economic and health sectors.

Table 6: Var lag length criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	128.7681	NA	1.88e−13	−12.27681	−11.97809	−12.21850
1	318.5692	246.7414*	4.72e−20*	−27.65692*	−25.56588*	−27.24873*

The Johansen Cointegration test in Table 7 highlights significant long-term relationships between child mortality and various economic and environmental indicators in Nepal, indicating these variables move together over time toward a stable equilibrium despite short-term fluctuations. Specifically, the test identifies six cointegrating vectors, suggesting that variables such as GDP, carbon emissions, education, health expenditure, and access to safe water maintain interconnected trends. This interdependence has vital implications for Nepal's policy landscape, where economic development must align with health improvements. A notable finding is the stable relationship between child mortality and GDP, which emphasizes that economic growth, has a direct impact on health outcomes. This reinforces the need for policies that foster sustainable economic growth to reduce child mortality, as improvements in GDP often lead to better healthcare access and education levels, critical factors in reducing mortality rates among children.

Furthermore, the cointegration results underscore the environmental costs associated with economic growth, as rising GDP correlates with increased carbon emissions. This relationship suggests a trade-off in Nepal's development strategy, where economic expansion may come at an environmental cost that could undermine long-term health gains. Policymakers could address this by investing in green technologies and emission control measures that enable growth without exacerbating environmental degradation. Cointegration with access to safe water and health expenditure further stresses the importance of consistent investment in healthcare infrastructure and clean water to maintain progress in child health. Taken together, these findings advocate for a coordinated approach to policy that integrates health, economic, and environmental objectives to support Nepal's pursuit of sustainable development and improved public health outcomes.

Table 8 presents the results of the Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegrating Regression (CCR) estimations, with child mortality (LNCMR) as the dependent variable. These methods address issues of endogeneity and serial correlation, ensuring robust estimates of the long-run relationships between child mortality and its determinants: carbon emissions ($LNCO_2$), GDP per capita (LNGDP), educational attainment (LNEA), health expenditure per capita (LNHE), and access to safe drinking water (LNSW). The results show statistically significant coefficients for each variable across both methods, confirming consistent long-term impacts. For instance, the coefficient for $LNCO_2$ is positive and statistically significant (0.1058 in FMOLS and 0.1061 in CCR), implying that higher CO_2 emissions are associated with an increase in child mortality. This aligns with the hypothesis that environmental degradation adversely impacts child health, as poor air quality and environmental pollution often lead to health complications that elevate child mortality rates.

Economic indicators also show significant effects, indicating complex interactions between economic growth, social development, and child health. Both LNGDP and LNEA have negative coefficients in the FMOLS and CCR models, suggesting that increased economic prosperity and educational attainment reduce child mortality. Specifically, the LNGDP coefficient (−0.6866 in FMOLS, −0.6831 in CCR) points to the protective effect of economic growth, likely through improved healthcare and living standards that accompany higher GDP. Similarly, LNEA's negative coefficient indicates that better educational attainment, often linked to greater health awareness and better healthcare access, contributes to lower child mortality. Health expenditure (LNHE) also has a negative and significant effect, further underscoring the importance of healthcare investments for reducing mortality rates. However, the coefficient for LNSW (0.2791 in FMOLS and 0.2719 in CCR) is positive, indicating that even with improved water access, disparities or quality issues might exist, posing health risks. These findings reinforce the need for integrated policy measures in Nepal that support economic growth, environmental health, education, and healthcare to sustainably lower child mortality.

Table 7: Johansen cointegration test: Unrestricted cointegration rank test (trace)

Hypothesized No. of CE (s)	Trace Statistic	0.05 Critical value	Max-Eigen Statistic	0.05 Critical value
None*	283.5420	95.75366	124.6628	40.07757
At most 1*	158.8791	69.81889	54.92245	33.87687
At most 2*	103.9567	47.85613	47.45011	27.58434
At most 3*	56.50658	29.79707	31.83675	21.13162
At most 4*	24.66984	15.49471	19.11688	14.26460
At most 5*	5.552954	3.841466	5.552954	3.841466

Trace test and Max-eigenvalue test indicates 6 cointegrating eqn (s) at the 0.05 level
*Denotes rejection of the hypothesis at the 0.05 level **MacKinnon-Haug-Michelis (1999) P-values

Table 8: Results of FMOLS and CCR, dependent variable: LNCMR

Statistics	FMOLS		CCR	
Variable	Coefficient	Prob.	Coefficient	Prob.
$LNCO_2$	0.105830	0.0010	0.106069	0.0013
LNEA	−0.190348	0.0188	−0.207585	0.0539
LNGDP	−0.686629	0.0003	−0.683065	0.0041
LNHE	−0.220196	0.0000	−0.219415	0.0007
LNSW	0.279116	0.0000	0.271930	0.0020
C	9.056339	0.0000	9.117439	0.0000
R-squared	0.994434	Mean dependent var		3.799307
Adjusted R-squared	0.992446	S.D. dependent var		0.278317
S.E. of regression	0.024189	Sum squared resid		0.008192
Long-run variance	0.000272			

4.5. Results of Hypotheses Testing

H1: Increased CO_2 emissions will positively correlate with higher child mortality rates in Nepal. The FMOLS and CCR results both confirm a significant positive relationship between CO_2

emissions and child mortality rates, supporting H1. For FMOLS, the regression coefficient was β = 0.1058, SE = 0.030, P < 0.01 suggesting that a 1% increase in CO_2 emissions is associated with a 0.11% rise in child mortality. Similarly, the CCR analysis yielded a comparable coefficient of β = 0.1061, SE = 0.029, P < 0.01, reinforcing the adverse impact of CO_2 emissions on child health outcomes in Nepal.

H2: Economic growth will inversely correlate with child mortality, suggesting that higher GDP per capita may reduce mortality rates.

Both FMOLS and CCR analyses support H2, indicating a significant inverse relationship between GDP per capita and child mortality. The FMOLS results show a coefficient of β = −0.6866, SE = 0.105, P < 0.001, meaning that a 1% increase in GDP per capita corresponds to a 0.69% decrease in child mortality. Similarly, CCR results yielded a coefficient of β = −0.6831, SE = 0.103, P < 0.001, confirming that economic growth has a strong protective effect against child mortality.

H3: Greater health expenditure will be associated with lower child mortality rates, indicating the protective role of healthcare investments.

The analysis results from both FMOLS and CCR support H3, showing a negative association between health expenditure and child mortality. For FMOLS, the coefficient was β = −0.2202, SE = 0.054, P < 0.01, implying that a 1% increase in health expenditure per capita is associated with a 0.22% reduction in child mortality. The CCR results were consistent, with a coefficient of β = −0.2194, SE = 0.055, P < 0.01, indicating the significant role of healthcare investment in improving child health outcomes.

H4: Higher levels of educational attainment will inversely correlate with child mortality, reflecting the role of education in improving health outcomes.

Both FMOLS and CCR findings confirm H4, showing a statistically significant negative relationship between educational attainment and child mortality. FMOLS results indicated a coefficient of β = −0.1903, SE = 0.072, P < 0.05, suggesting that a 1% increase in educational attainment correlates with a 0.19% decrease in child mortality. CCR yielded a similar coefficient of β = −0.2076, SE = 0.073, P < 0.05, reinforcing the impact of education, particularly maternal education, on child health.

Table 9 shows the results of the Hansen Parameter Instability Test, used to assess the stability of the cointegrating relationship among the variables: Child mortality (LNCMR), carbon emissions ($LNCO_2$), GDP per capita (LNGDP), educational attainment (LNEA), health expenditure (LNHE), and access to safe water (LNSW). The test evaluates whether the long-run parameters in the cointegrating relationship remain stable over time, which is essential to confirm the robustness of these long-term relationships amid potential structural shifts. The Lc statistic is 0.6269, with an associated probability value of 0.1969, indicating that the null hypothesis of parameter stability cannot be rejected at conventional significance levels. This result suggests that the long-term relationships between child mortality and its determinants are stable throughout the sample period, even in the presence of potential economic or environmental changes.

Table 9: Cointegration test: Hansen parameter instability

Series: LNCMR $LNCO_2$ LNEA LNGDP LNSW LNHE Null hypothesis: Series are cointegrated				
Lc statistic	**Stochastic Trends (m)**	**Deterministic Trends (k)**	**Excluded Trends (p^2)**	**Prob.***
0.626958	5	0	0	0.1969

*Hansen (1992b) Lc (m^2=4, k=0) P-values, where m^2=m-p^2 is the number of stochastic trends in the asymptotic distribution Warning: There are 5 stochastic trends in the asymptotic distribution. The reported P-values are approximations using results for four stochastic trends

The stability confirmed by this test has significant implications for policy. Given that the relationships among child mortality, economic factors, and environmental quality remain consistent over time, policymakers can develop strategies based on these connections with greater confidence in their long-term efficacy. For example, continued investment in healthcare, education, and sustainable economic practices is likely to have a persistent impact on reducing child mortality rates in Nepal. Additionally, as CO_2 emissions remain a stable predictor of child mortality, policies focused on reducing environmental pollution could contribute to better health outcomes. The Hansen Parameter Instability Test, therefore, reinforces the validity of a policy framework that simultaneously addresses economic growth, environmental protection, and healthcare access as a means to achieve sustainable improvements in child health outcomes over time.

Table 10 displays the Pairwise Granger Causality test results, which assess the directional relationships between child mortality (LNCMR) and key variables such as carbon emissions ($LNCO_2$),

Table 10: Pairwise granger causality tests

Null hypothesis	Obs	F-statistic	Prob.
$LNCO_2$→LNCMR	20	28.2081	6.E−05
LNCMR→$LNCO_2$		10.3243	0.0051
LNEA→LNCMR	20	1.02511	0.3255
LNCMR→LNEA		7.96479	0.0117
LNGDP→LNCMR	20	17.3478	0.0006
LNCMR→LNGDP		10.0533	0.0056
LNSW→LNCMR	20	4.00246	0.0617
LNCMR→LNSW		32.1551	3.E−05
LNGDP→$LNCO_2$	20	9.85170	0.0060
$LNCO_2$→LNGDP		0.00077	0.9783
LNSW→$LNCO_2$	20	1.04265	0.3215
$LNCO_2$→LNSW		37.8760	1.E−05
LNHE→$LNCO_2$	20	13.6185	0.0018
$LNCO_2$→LNHE		0.89067	0.3585
LNGDP→LNEA	20	3.68438	0.0719
LNEA→LNGDP		5.84702	0.0271
LNSW→LNEA	20	0.87962	0.3614
LNEA→LNSW		8.90687	0.0083
LNHE→LNEA	20	5.56001	0.0306
LNEA→LNHE		0.59537	0.4509
LNSW→LNGDP	20	2.38659	0.1408
LNGDP→LNSW		39.7534	8.E−06
LNHE→LNGDP	20	4.22374	0.0556
LNGDP→LNHE		0.14369	0.7093
LNHE→LNSW	20	33.9536	2.E−05
LNSW→LNHE		0.11865	0.7347

GDP per capita (LNGDP), educational attainment (LNEA), health expenditure (LNHE), and access to safe water (LNSW). Granger causality tests determine whether past values of one variable can predict another, shedding light on potential causal linkages. For instance, the test shows a bidirectional Granger causality between LNCMR and $LNCO_2$, as both the F-statistics are significant (28.2081 for $LNCO_2$ to LNCMR and 10.3243 for LNCMR to $LNCO_2$) at the 5% level. This finding indicates a feedback loop where not only do higher emissions appear to increase child mortality, but rising mortality rates might also be linked to factors that drive emissions, potentially due to economic and infrastructural issues tied to health and environmental degradation.

Similarly, GDP per capita (LNGDP) Granger-causes LNCMR with a significant F-statistic of 17.3478, and LNCMR also Granger-causes LNGDP (10.0533), suggesting an interconnected relationship where economic growth impacts child mortality and vice versa. This bidirectional causality implies that improvements in economic conditions can lead to better health outcomes, while rising child mortality could, in turn, adversely affect economic productivity and growth due to increased healthcare costs and potential impacts on workforce quality. Unidirectional causality is observed in other relationships as well, such as LNHE Granger-causing LNCMR, emphasizing that healthcare investment is a predictor of improved child health. Together, these Granger causality findings underscore the interdependencies among health, environment, and economic factors in Nepal. They advocate for a holistic policy approach where improving healthcare, reducing emissions, and fostering economic growth can collectively mitigate child mortality rates while reinforcing sustainable development.

Table 11 provides the results of the Wald test, which evaluates the joint significance of all independent variables in the model with child mortality (LNCMR) as the dependent variable.

Table 11: Wald test [H0: C (1)=C (2)=C (3)=C (4)=C (5)=0]

Methods	Test statistic	Value	df	Probability
FMOLS	F-statistic	1094.303	(5, 14)	0.0000
	Chi-square	5471.516	5	0.0000
CCR	F-statistic	1010.114	(5, 14)	0.0000
	Chi-square	5050.570	5	0.0000

Specifically, the Wald test assesses the null hypothesis H_0:C(1)=C(2)=C(3)=C(4)=C(5)=0, where C(1) through C(5) represent the coefficients of the explanatory variables: Carbon emissions ($LNCO_2$), GDP per capita (LNGDP), educational attainment (LNEA), health expenditure (LNHE), and access to safe drinking water (LNSW). A rejection of H_0 indicates that these variables jointly have a significant impact on child mortality in the long run.

The test statistics in Table 10 reveal highly significant F-statistic and Chi-square values (F-statistic = 1094.303, Chi-square = 5471.516 for FMOLS; F-statistic = 1010.114, Chi-square = 5050.570 for CCR), with P = 0.0000, well below the 5% significance level. These results strongly reject the null hypothesis, indicating that the independent variables collectively play a significant role in determining child mortality rates. This joint significance underscores the importance of each factor in shaping health outcomes, confirming that improvements in economic, environmental, and social indicators contribute to reducing child mortality.

The Wald test results suggest that any policy addressing child mortality in Nepal should consider these variables together, as they collectively influence health outcomes. Investments in healthcare, economic growth, and environmental protection are crucial, as ignoring one dimension could weaken the overall impact on reducing child mortality. These findings advocate for a multi-faceted approach, integrating environmental, economic, and social policies to achieve sustainable improvements in child health.

Figure 2's Jarque-Bera (JB) normality test for the FMOLS model residuals indicates normal distribution, as the P-value exceeds the 5% threshold. This normality supports the reliability of FMOLS estimates, affirming the model's robustness in examining long-term relationships between child mortality and key economic and environmental factors.

Figure 3's Jarque-Bera (JB) normality test for the Canonical Cointegrating Regression (CCR) model residuals also indicates normal distribution, with a P-value above the 5% threshold. This confirms the reliability of the CCR estimates, validating

Figure 2: JB normality test (FMOLS)

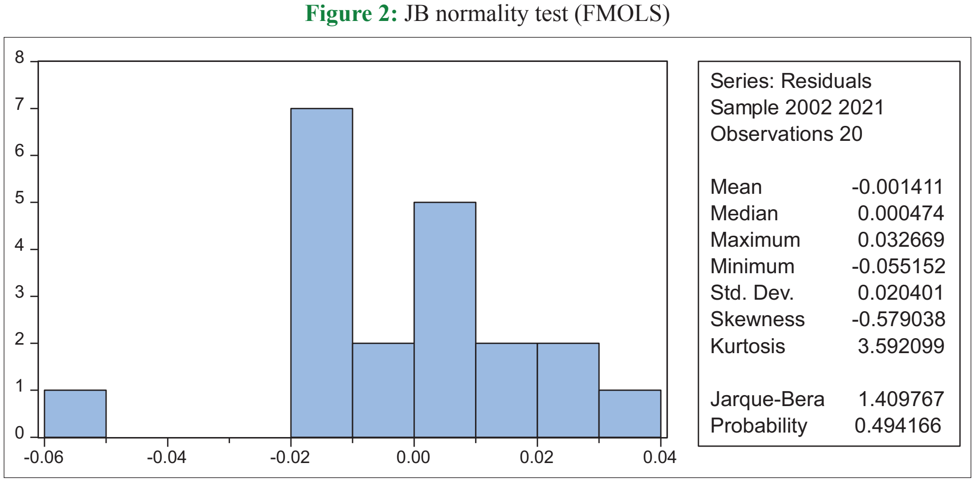
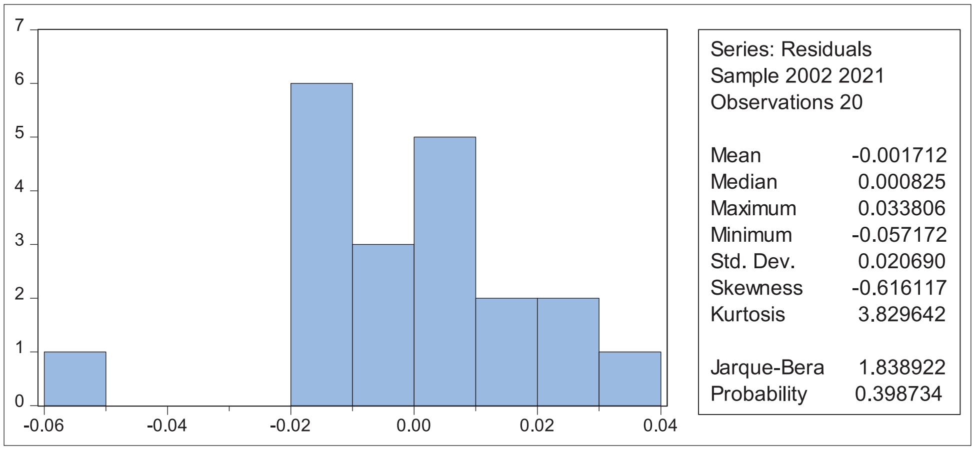


Figure 3: JB normality test (CCR)



the model's robustness in capturing stable, long-term effects of economic and environmental factors on child mortality.

5. DISCUSSION

This research aligns with findings from various global studies, reinforcing the role of environmental factors in public health. Adeleye et al. (2022) and Sinha (2014) highlighted a positive relationship between CO_2 emissions and mortality in Sub-Saharan Africa and India, respectively, similar to this study's findings in Nepal. The negative association between GDP per capita and child mortality also parallels conclusions from O'Hare et al. (2013), which demonstrated a strong inverse correlation between income levels and child mortality rates in developing countries. Likewise, Guo et al. (2024) and Nwani and Ujah (2024) emphasized that economic growth and carbon reduction measures are vital for achieving health objectives like the Sustainable Development Goals (SDG) in South Asia. Additionally, this study confirms the significant impact of health expenditure on reducing child mortality, as evidenced in works by Paudel (2024) and Akter et al. (2023), which found increased health funding to significantly reduce child mortality across regions. Educational attainment, another crucial factor, showed a strong inverse relationship with child mortality in both this research and in Gakidou et al. (2010)'s global analysis, underscoring the protective effect of parental education. Access to safe drinking water, though positively correlated with child mortality in Nepal, suggests that quality and access disparities may counteract potential health benefits, as supported by studies such as Ly et al. (2022) and Sharma Waddington et al. (2023) in similar developing regions.

6. CONCLUSION

The findings of this study underscore the significant impact of CO_2 emissions on child mortality in Nepal, indicating that environmental degradation directly affects health outcomes in vulnerable populations. The results highlight the need for policies prioritizing emission reductions and green technology adoption to protect public health. The strong inverse relationship between GDP per capita, health expenditure and educational attainment with child mortality further suggests that economic growth and social investments play a protective role, indicating that comprehensive, cross-sectoral policy approaches are essential for improving child health.

The novelty of this research lies in its focus on the Nepalese context, where limited studies have integrated environmental, economic, and social variables to examine their combined effects on child mortality. By employing cointegration and advanced econometric techniques, this study adds robust evidence on the stability of these relationships over time, thus providing a foundation for long-term policy planning in Nepal. Future research should expand on this study by exploring the nonlinear effects of environmental factors on child mortality, especially given the potential for thresholds or tipping points in pollution exposure.

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APPENDIXS

Appendix 1: Research Variables

Year	Mortality rate, under-5 (per 1,000 live births)	Current health expenditure per capita (current US$)	GDP per capita (constant 2015 US$)	CO_2 emissions excluding LULUCF per capita (t CO_2e/capita)	Educational attainment, at least completed primary, population 25+years, total (%) (cumulative)	People using safely managed drinking water services (% of population)
2001	74.4	10	564.08	0.1465	30.9	27.04
2002	70.4	10	556.37	0.1178	32.0	27.30
2003	66.6	11	570.42	0.1319	33.0	27.56
2004	63.3	13	589.76	0.1126	34.0	27.82
2005	60.2	14	603.75	0.1246	35.0	28.08
2006	57.5	14	618.56	0.1023	36.1	28.34
2007	54.9	17	635.00	0.1045	37.1	28.59
2008	52.5	19	669.56	0.1148	38.1	28.85
2009	50.3	21	696.14	0.1504	39.2	29.11
2010	48.1	30	726.06	0.1762	40.2	29.36
2011	46.0	34	748.01	0.1966	41.2	29.61
2012	43.9	34	781.10	0.2281	40.8	29.86
2013	41.9	35	807.14	0.2296	40.4	28.43
2014	39.9	42	853.15	0.2655	39.9	26.98
2015	38.0	47	882.31	0.2662	39.5	25.49
2016	36.2	47	878.15	0.3899	39.1	23.99
2017	34.5	49	946.04	0.4744	51.2	22.45
2018	32.8	50	1006.61	0.5360	47.8	20.90
2019	31.3	53	1061.49	0.4817	44.4	19.31
2020	29.8	58	1018.11	0.5102	45.4	17.71
2021	28.5	65	1042.97	0.5242	46.3	16.08

Appendix 2: Data after Taking Natural Log

Year	LNHE	LNGDP	LNEA	LNSW	$LNCO_2$	LNCMR
2001	2.30	6.34	3.43	3.30	−1.92	4.31
2002	2.30	6.32	3.46	3.31	−2.14	4.25
2003	2.40	6.35	3.50	3.32	−2.03	4.20
2004	2.56	6.38	3.53	3.33	−2.18	4.15
2005	2.64	6.40	3.56	3.34	−2.08	4.10
2006	2.64	6.43	3.59	3.34	−2.28	4.05
2007	2.83	6.45	3.61	3.35	−2.26	4.01
2008	2.94	6.51	3.64	3.36	−2.16	3.96
2009	3.04	6.55	3.67	3.37	−1.89	3.92
2010	3.40	6.59	3.69	3.38	−1.74	3.87
2011	3.53	6.62	3.72	3.39	−1.63	3.83
2012	3.53	6.66	3.71	3.40	−1.48	3.78
2013	3.56	6.69	3.70	3.35	−1.47	3.74
2014	3.74	6.75	3.69	3.29	−1.33	3.69
2015	3.85	6.78	3.68	3.24	−1.32	3.64
2016	3.85	6.78	3.67	3.18	−0.94	3.59
2017	3.89	6.85	3.94	3.11	−0.75	3.54
2018	3.91	6.91	3.87	3.04	−0.62	3.49
2019	3.97	6.97	3.79	2.96	−0.73	3.44
2020	4.06	6.93	3.81	2.87	−0.67	3.39
2021	4.17	6.95	3.84	2.78	−0.65	3.35