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Research Article

Time-Series Econometric Analysis of Factors Associated with Under-Five Mortality in Senegal

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Abstract

Under-five mortality remains a major public health challenge in sub-Saharan Africa, and Senegal is still far from the Sustainable Development Goal 3.2 target set for 2030. This study examines the factors associated with under-five mortality in Senegal over the period 2000-2023, using twenty-four annual observations drawn from the Demographic and Health Surveys and from official statistics of the National Agency for Statistics and Demography. A multiple linear regression model estimated by ordinary least squares is used. The explanatory variables cover malaria control (insecticide-treated net coverage), residential structure, children's nutritional status (stunting and acute malnutrition), and maternal human capital (schooling). The model has high explanatory power ($R^2 = 0.964$) and identifies two statistically significant factors with a negative effect on under-five mortality: insecticide-treated net use ($\beta = -0.676$; $p = 0.003$) and maternal schooling ($\beta = -2.575$; $p < 0.001$). The residuals meet the normality and homoscedasticity assumptions, and collinearity among the regressors remains moderate. Ramsey's specification test points to possible non-linearity, and the trending nature of the series calls for cautious interpretation of the coefficients; the two main effects are nonetheless robust to Newey-West standard errors. The findings support strengthening girls' education and vector-control programmes as central levers for reducing child mortality, together with sustained investment in health information systems for policy evaluation.

Keywords

Under-five Mortality, Senegal, Linear Regression, Ordinary Least Squares, Malaria, Maternal Schooling, Time Series

1. Introduction

Child mortality is one of the most important indicators for assessing progress in a population's education and health. It is a component of the Human Development Index (HDI) developed by the United Nations, which is why it is closely monitored worldwide, particularly in developing countries. In the

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World Health Organization (WHO) African Region, infant mortality is six times higher than in the European Region [1]. According to the World Bank [2], deaths of children under five are concentrated mainly in sub-Saharan Africa and South Asia. Suzuki and Kashiwase [3] showed that, in 2018, 80% of under-five deaths occurred in this part of the world. Sub-Saharan Africa alone accounted for 54% of these deaths (2,868,000) and South Asia for 28% (1,475,000). In sub-Saharan Africa, one child in thirteen does not survive to age five [2]. West and Central Africa remain the regions most affected by this excess mortality. According to the United Nations Children's Fund (UNICEF) [2], five million children died worldwide before their fifth birthday in 2021, and about 40% of these deaths occurred in West and Central Africa, that is, 1.9 million children under five. In other words, in a region that is home to 14% of the world's under-five population, a child under five died every 17 seconds in 2021. At an estimated 92 per 1000, this is the highest under-five mortality rate in the world. The neonatal mortality rate, at 30.5 per 1000, is declining more slowly. Despite targeted policies to improve access to care for children under five within a universal health coverage framework, most of these countries will not reach Sustainable Development Goal (SDG) 3.2 on under-five mortality by 2030, set at fewer than 25 per 1000 live births. Worldwide, meeting this target would save 6.9 million children, including more than 4.8 million aged 1 to 59 months and 2.1 million newborns.

In Senegal, despite numerous initiatives to improve access to care for vulnerable groups, under-five mortality remains a public health problem, especially neonatal mortality, notwithstanding the steady declines recorded over several years [4]. With a rate of 40 per 1000 live births in 2023 [5], the country is still far from SDG 3.2 for 2030. Of every 1000 children born alive in Senegal, 40 will not reach their fifth birthday [6]. This under-five mortality shows regional disparities ranging from 20 to 77 per 1000 live births according to the most recent Demographic and Health Survey (DHS), published in 2023. Kolda is the most affected region, at 77 per 1000, followed by Sédhiou at 71 per 1000. Kédougou and Kaffrine record 63 and 62 per 1000 respectively, whereas Kaolack and Saint-Louis, at 29 and 31 per 1000, fall below the national average of 40 per 1000. Ziguinchor records the lowest rate at 20 per 1000, followed by Dakar at 25 per 1000. These wide gaps show that, in several regions, children continue to die despite free-care policies intended to improve access and equity in health services.

The factors associated with under-five mortality are varied, and some are avoidable. A review of the databases of the National Agency for Statistics and Demography (ANSD) and of studies on child mortality from 2000 to 2023 allowed us to identify the main factors associated with mortality among children aged 0 to 5 years in Senegal over the study period. These factors are related to disease (malaria, diarrhoea, acute respiratory infections). They are also socioeconomic, environmental, and maternal in nature [7].

This situation raises the question of the efficiency and effectiveness of free-care policies in Senegal. In other words, has free care for vulnerable groups, particularly children under five, produced results commensurate with the resources committed? Should control strategies be revised to speed up the reduction of morbidity and mortality among children under five in Senegal? These questions lead us to examine the causes of death in the 0-to-5 age group in order to better target public programmes aimed at improving population health. In a context of increasingly scarce resources and steadily rising health needs, a stronger focus on results-based management is warranted.

This study aims to conduct an econometric analysis of the factors associated with mortality among children under five. It is intended to help decision-makers improve free-care programmes and design new mechanisms for reducing under-five mortality.

2. Materials and Methods

To analyse the factors associated with mortality among children aged 0 to 5 years in Senegal, we use an econometric model. This section presents the model, the variables, the data, and the estimation strategy.

2.1. Model Specification

To explain the factors associated with under-five mortality (U5M), we used a multiple linear regression estimated by ordinary least squares (OLS). The model describes the relationship between under-five mortality and its associated factors: the use of insecticide-treated nets (ITNs), malnutrition, schooling, residence, and stunting. Assuming that the variables satisfy this relationship, the model equation is:

$$U5M_t = C + \alpha_1 EDSMII_t + \alpha_2 RMRUR_t + \alpha_3 MALNUT_t + \alpha_4 RCM5_t + \alpha_5 MSCOL_t + \varepsilon_t$$

where t indexes the years (t = 2000, …, 2023), C is the constant, EDSMII, RMRUR, MALNUT, RCM5 and MSCOL are the explanatory variables defined in Table 1, α_1 to α_5 are the coefficients of the explanatory variables, and ε_t is the error term, assumed independently and identically distributed (i.i.d.) with zero mean and constant variance.

2.2. Variables and Data

The model comprises five explanatory variables and one dependent variable, defined in Table 1.

The data form a time series covering the period 2000-2023, that is, 24 annual observations. They come from Senegal's Demographic and Health Surveys (DHS) and from the official statistics of the National Agency for Statistics and Demography (ANSD).

Table 1. Definition of the model variables.

Code	Label	Definition	Role
U5M	Under-five mortality	Under-five mortality rate (per 1000 live births)	Dependent
EDSMII	ITN coverage	% of children <5 who slept under an insecticide-treated net (ITN)	Explanatory
RMRUR	Rural residence	% of children <5 living in rural areas	Explanatory
RCM5	Stunting	Prevalence of stunting among children <5 (%)	Explanatory
MALNUT	Acute malnutrition	Prevalence of acute malnutrition (wasting) among children <5 (%)	Explanatory
MSCOL	Maternal schooling	% of mothers aged 15-49 with schooling	Explanatory

Source: compiled from DHS and ANSD data, Senegal (2000-2023).

Ethical considerations. This study relied exclusively on publicly available, aggregate secondary data from the Senegal DHS and from ANSD official statistics, which contain no individual identifiers. Ethical review and approval were therefore not required.

2.3. Econometric Strategy

The approach comprises three steps: (i) univariate and bivariate descriptive analysis (summary statistics, correlation matrix, time plots); (ii) OLS estimation of the model and analysis of the coefficients; and (iii) a set of diagnostic tests covering multicollinearity (variance inflation factor, VIF), residual normality (Shapiro-Wilk, Jarque-Bera), homoscedasticity (Breusch-Pagan, White), autocorrelation (Durbin-Watson, Breusch-Godfrey), specification (Ramsey Regression Equation Specification Error Test, RESET), and stationarity (Augmented Dickey-Fuller). Where autocorrelation or heteroscedasticity is present, re-estimation with Newey-West (heteroscedasticity and autocorrelation consistent, HAC) standard errors is used.

2.4. Preliminary Descriptive Analysis

2.4.1. Descriptive Statistics

Table 2. Descriptive statistics of the model variables (n = 24).

Variable	Mean	Std. dev.	Minimum	Maximum
U5M	78.79	35.85	37.00	145.00
EDSMII	32.77	21.00	1.67	66.60
RMRUR	64.81	3.13	51.21	66.10
RCM5	19.81	3.52	14.70	27.00
MALNUT	8.68	1.16	5.90	10.20
MSCOL	42.85	8.78	29.00	56.00

Table 2 highlights several patterns. Under-five mortality (U5M) averages 78.8 per 1000 over the period, with a wide range (37 to 145 per 1000), reflecting the decline observed since 2000. Insecticide-treated net use (EDSMII) rose from 1.67% to 66.6%, in line with the expansion of malaria-control programmes. Maternal schooling (MSCOL) increased from 29% to 56%. The nutritional indicators (RCM5, MALNUT) and residential structure (RMRUR) show more limited variability. The low dispersion of RMRUR (standard deviation 3.13) and MALNUT (standard deviation 1.16) limits from the outset their capacity to explain variation in mortality.

2.4.2. Time Trend

Figure 1 Trend in the under-five mortality rate in Senegal

(2000-2023).

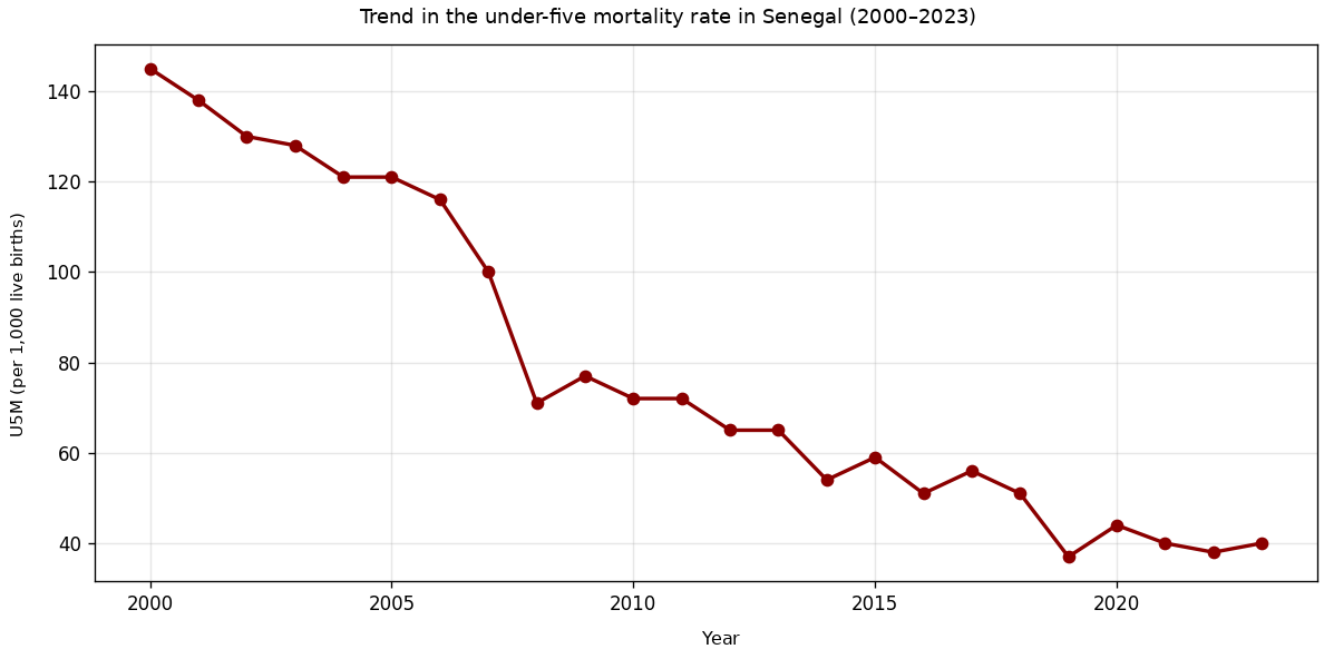


Figure 1. *Shows the near-monotonic downward trend in the U5M rate over the period. This trend reflects the health progress achieved in Senegal, and also the need to identify the levers that contributed to this improvement.*

2.4.3. Correlation Matrix

Table 3. *Pearson correlation matrix.*

	U5M	EDSMII	RMRUR	RCM5	MALNUT	MSCOL
U5M	1.000	-0.932	0.117	0.404	0.435	-0.966
EDSMII	-0.932	1.000	0.067	-0.324	-0.492	0.886
RMRUR	0.117	0.067	1.000	-0.144	-0.454	-0.170
RCM5	0.404	-0.324	-0.144	1.000	0.399	-0.424
MALNUT	0.435	-0.492	-0.454	0.399	1.000	-0.476
MSCOL	-0.966	0.886	-0.170	-0.424	-0.476	1.000

The matrix shows a strong negative association between U5M and insecticide-treated net use ($r = -0.932$) and maternal schooling ($r = -0.966$). Stunting (RCM5, $r = 0.404$) and rural residence (RMRUR, $r = 0.117$) show positive correlations with mortality, consistent with theoretical expectations. These bivariate correlations do not prejudge the net effects, which are clarified by the multiple regression. The two main regressors are themselves strongly correlated (EDSMII-MSCOL, $r = 0.886$).

3. Results

3.1. Regression Estimates

Table 4 presents the OLS estimation results.

Table 4. OLS estimation results for the under-five mortality model.

Variable	Coefficient	Std. error
ITN coverage (EDSMII)	-0.6761***	(0.1978)
Rural residence (RMRUR)	0.1143	(0.7744)
Stunting (RCM5)	0.3908	(0.5427)
Acute malnutrition (MALNUT)	-2.1967	(2.0445)
Maternal schooling (MSCOL)	-2.5750***	(0.5477)
Constant	215.2046**	(78.5270)
Observations (n)	24	
R^2	0.9638	
Adjusted R^2	0.9538	
F-statistic (p-value)	95.97	(< 0.001)

Notes: Dependent variable: U5M (under-five mortality rate, per 1000). *** p < 0.01; ** p < 0.05; * p < 0.10. Estimation method: Ordinary Least Squares (OLS).

3.2. Goodness of Fit

The model shows a strong goodness of fit. R^2 reaches 0.9638, meaning that 96.4% of the variance in under-five mortality is explained by the five variables. The adjusted R^2 (0.9538), which penalises the addition of regressors, confirms the robustness of this fit.

The F-statistic (F = 95.97; p < 0.001) rejects the null hypothesis that all coefficients are jointly zero. The model is therefore globally significant at the 1% level. The Akaike (AIC = 171.22) and Schwarz (BIC = 178.29) information criteria can serve as references for comparison with alternative specifications.

3.3. Interpretation of the Coefficients

ITN coverage (EDSMII). The coefficient on insecticide-treated net use is −0.6761 and significant at the 1% level (p = 0.003). Its negative sign indicates that a one-percentage-point increase in ITN use is associated, all else equal, with a 0.68-point decrease in the under-five mortality rate.

Maternal schooling (MSCOL). The MSCOL coefficient, equal to −2.5750 and significant at the 1% level (p < 0.001), has the largest magnitude in the model. A one-percentage-point increase in maternal schooling is associated with a 2.58-point reduction in the U5M rate, all else equal.

Non-significant variables. The coefficients on rural residence (RMRUR, β = 0.1143; p = 0.884), stunting (RCM5, β = 0.3908; p = 0.481), and acute malnutrition (MALNUT, β = −2.1967; p = 0.297) are not significant at the conventional 5% level. As such, their effect cannot be statistically distinguished from zero in this model. This lack of significance may reflect the small sample size (n = 24), the correlation between these variables and the other regressors, or limited variation over time. It does not mean that there is no real effect, but that it cannot be detected within this framework.

3.4. Diagnostic Tests

OLS estimates are valid insofar as the classical assumptions of the linear model (Gauss-Markov) hold. This subsection checks these assumptions.

3.4.1. Multicollinearity

Table 5. Variance inflation factors (VIF).

Variable	VIF	1/VIF
EDSMII	6.684	0.150
RMRUR	2.282	0.438
RCM5	1.415	0.707
MALNUT	2.174	0.460
MSCOL	8.960	0.112

Table 5 shows that all VIFs are below 10. The maximum value (8.96), for MSCOL, is close to the critical threshold of 10 and indicates moderate collinearity with the other variables, without compromising the estimates. This collinearity stems from the strong correlation between MSCOL and EDSMII (r = 0.886); it inflates the standard errors of these two variables, so their significance nonetheless points to robust effects.

3.4.2. Residual Normality

Table 6. Residual normality tests.

Test	Statistic	p-value	Decision (H_0: normality)
Shapiro-Wilk	0.9656	0.5615	Not rejected
Jarque-Bera	0.5938	0.7431	Not rejected
Skewness	-0.3748	—	Close to 0
Kurtosis	2.8211	—	Close to 3

The Shapiro-Wilk (W = 0.9656; p = 0.562) and Jarque-Bera (JB = 0.5938; p = 0.743) tests do not reject residual normality. The skewness and kurtosis coefficients are close to their theoretical values (0 and 3). This supports the use of t- and F-tests for inference.

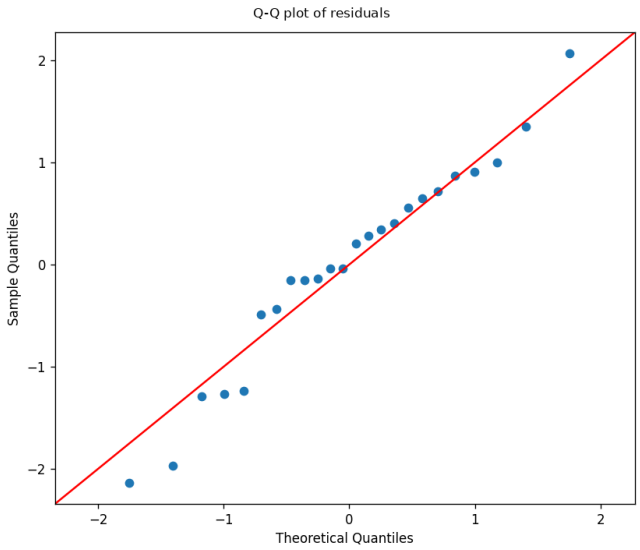


Figure 2. Quantile-Quantile (Q-Q) plot of the residuals.

3.4.3. Heteroscedasticity

Table 7. Heteroscedasticity tests.

Test	LM statistic	p-value	Decision (H_0: homoscedasticity)
Breusch-Pagan	4.9993	0.4160	Not rejected
White	23.8204	0.2503	Not rejected

The Breusch-Pagan (Lagrange multiplier, LM = 5.00; p = 0.416) and White (LM = 23.82; p = 0.250) tests do not reject homoscedasticity. Residual variance can therefore be regarded as constant. This is corroborated by the plot of residuals against fitted values (Figure 3), which shows no systematic pattern.

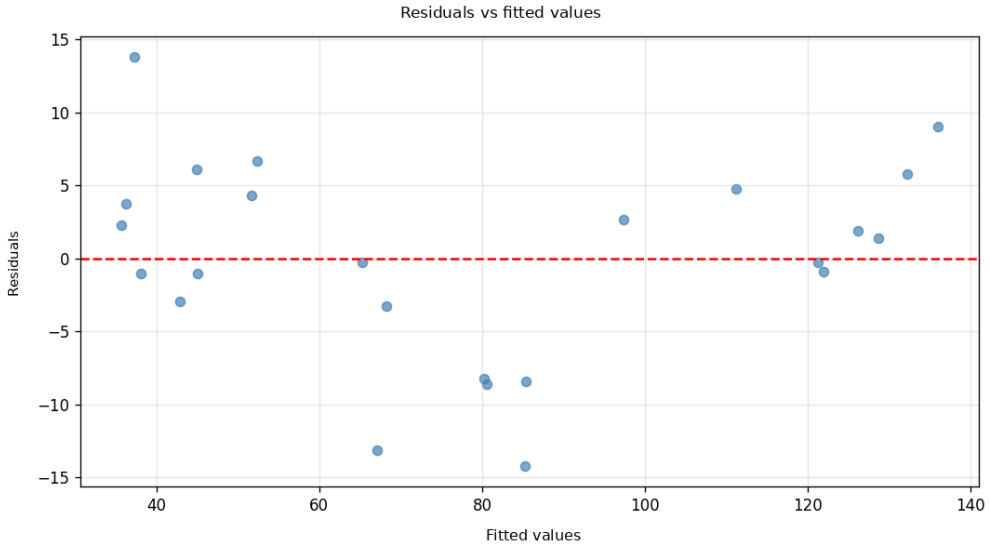


Figure 3. Residuals versus fitted values.

3.4.4. Residual Autocorrelation

Table 8. Residual autocorrelation tests.

Test	Statistic	p-value	Decision
Durbin-Watson	1.1302	—	Inconclusive region (dL ≈ 0.93; dU ≈ 1.90)
Breusch-Godfrey (2 lags)	4.2652	0.1185	Not rejected (no autocorrelation)

Note: H_0: no residual autocorrelation. A Durbin-Watson statistic close to 2 indicates no first-order autocorrelation.

For n = 24 and k = 5, the Durbin-Watson statistic (1.130) lies in the inconclusive region between the bounds dL ≈ 0.93 and dU ≈ 1.90, so the test is inconclusive. The more general Breusch-Godfrey test (LM = 4.27; p = 0.119) does not reject

the null hypothesis at the 5% level. As a precaution, a re-estimation with Newey-West standard errors (robust to heteroscedasticity and autocorrelation) is reported in Section 3.5.

3.5. Re-estimation With Robust Standard Errors

Given the inconclusive result on autocorrelation (Section 3.4.4), the model is re-estimated with Newey-West (HAC) standard errors, robust to heteroscedasticity and autocorrelation.

Table 9. *Model estimation with Newey-West (HAC) standard errors.*

Variable	Coefficient	HAC std. error
ITN coverage (EDSMII)	-0.6761***	(0.1987)
Rural residence (RMRUR)	0.1143	(0.4522)
Stunting (RCM5)	0.3908	(0.5376)
Acute malnutrition (MALNUT)	-2.1967	(2.3074)
Maternal schooling (MSCOL)	-2.5750***	(0.3980)
Constant	215.2046***	(53.5424)
Observations (n)	24	
R^2	0.9638	
Adjusted R^2	0.9538	

Notes: Newey-West (HAC) standard errors with 2 lags in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

Comparing Tables 4 and 9 shows that the main conclusions are unchanged under robust standard errors. EDSMII and MSCOL remain significant at the 1% level, with coefficients of identical magnitude. This robustness increases confidence in the results. The estimated effects of malaria control and maternal schooling on U5M are not artefacts of autocorrelation or heteroscedasticity.

4. Discussion

Two variables account for most of the model's explanatory power: insecticide-treated net coverage and maternal schooling. The nutritional indicators and the rural population share, by contrast, are not statistically different from zero. This result is in line with the literature on child survival in sub-Saharan Africa, subject to the limitations of short and strongly trending series, discussed at the end of this section.

Maternal schooling. Maternal schooling carries the greatest weight in the model. Through the mechanism described by Caldwell [7, 8], an educated mother recognises danger signs earlier, seeks care more often, and has greater say in household decisions. Recent estimates point in the same direction. Gakidou et al. [9] attribute about half of the global decline in under-five mortality between 1970 and 2009 to the rise in female education alone, and Balaj et al. [10] estimate an approximately 3% reduction in the risk of death for each additional year of maternal schooling. The Senegalese coefficient is of the same order of magnitude. It is a reminder that, in Senegal as elsewhere, educating girls is also a child-survival policy.

Malaria control and insecticide-treated nets. The protective effect of insecticide-treated nets confirms the value of the malaria-control strategy pursued since the early 2000s. Lengeler's Cochrane review [11] puts the reduction in all-cause mortality among children under five sleeping under a net at close to 17%, and Bhatt et al. [12] identify nets as the main driver of the decline in Plasmodium falciparum in Africa between 2000 and 2015. Senegal provides direct evidence: Trape et al. [13] linked the new malaria-control policies to the fall in child mortality, and Thwing et al. [14] described the first national long-lasting insecticide-treated net (LLIN) distribution campaign. The result is also consistent with Ndiaye et al. [15], whose 1980-2015 analysis showed that greater curative coverage was not enough to reduce mortality and that prevention should be prioritised. Our model recovers this effect at the aggregate national level, whereas earlier evaluations focused mainly on households.

Non-significant variables. That nutrition and rural residence do not emerge may seem surprising, given how well established their role is elsewhere. At the individual level, undernutrition is a major cause of death: Black et al. [16] attribute nearly 45% of deaths before age five to it, and the pooled analysis by Olofin et al. [17] shows a risk that rises with the severity of stunting. Our result does not contradict this link; it reflects the nature of the data. Over the period, stunting, acute malnutrition, and the rural share vary too little for a time-series model to isolate their own effect. National aggregation also masks the substantial regional gaps in the 2023 DHS, where mortality ranges from 20 to 77 per 1000. Finally, because these variables are correlated with schooling and net coverage, the latter capture part of their influence. The lack of significance is therefore a matter of statistical power and level of aggregation, not of absence of effect.

Scope and limitations. The R^2 of 0.964 is striking but should not be over-interpreted. The three key series follow marked trends, and in the absence of stationarity and cointegration tests, a very high R^2 combined with a Durbin-Watson of 1.13 leaves open the possibility of a spurious regression. The coefficients then describe long-run associations rather than strictly causal effects. The RESET test points in the same direction, indicating possible non-linearity, for instance a threshold effect as net coverage scales up. To this are added data aggregated at the national level, which cannot be transposed as such to the individual level, and a sample of twenty-four points that leaves few degrees of freedom. These reservations do not call

into question the two main effects, which are robust to Newey-West standard errors; they only bound what can be concluded from them. They are consistent with recent work on the social determinants of under-five mortality in sub-Saharan Africa [18].

5. Conclusions

This study examined the factors associated with under-five mortality in Senegal over 2000-2023 using a multiple linear regression model estimated by OLS. The model has a high goodness of fit ($R^2 = 0.964$) and satisfies the assumptions of normality, homoscedasticity, and absence of severe multicollinearity; the RESET test, however, points to possible non-linearity, and the stationarity of the series remains to be established. Two variables stand out as statistically and economically significant: maternal schooling (marginal effect −2.58) and insecticide-treated net use (marginal effect −0.68). These results hold after re-estimation with robust (Newey-West) standard errors.

For public policy, these results support strengthening the schooling and literacy of girls and women, which is the main lever for reducing under-five mortality identified in this study; continuing and scaling up malaria-control programmes, in particular the distribution of insecticide-treated nets, whose effectiveness is confirmed here; and sustained investment in health information and monitoring systems, so that long and reliable series are available for policy evaluation.

Abbreviations

AIC	Akaike Information Criterion
ANSD	National Agency for Statistics and Demography (Agence Nationale De La Statistique Et De La Démographie)
BIC	Bayesian (Schwarz) Information Criterion
DHS	Demographic and Health Survey
EDSMII	Percentage of Children Under Five Who Slept Under an Insecticide-Treated Net
HAC	Heteroscedasticity and Autocorrelation Consistent
HDI	Human Development Index
ITN	Insecticide-Treated Net
LLIN	Long-Lasting Insecticide-Treated Net
LM	Lagrange Multiplier
MALNUT	Prevalence of Acute Malnutrition (Wasting) Among Children Under Five
MSCOL	Percentage of Mothers Aged 15-49 Years with Schooling
OLS	Ordinary Least Squares
Q-Q	Quantile-Quantile
RCM5	Prevalence of Stunting Among Children Under Five
RESET	Regression Equation Specification Error Test
RMRUR	Percentage of Children Under Five Living in Rural Areas
SDG	Sustainable Development Goal
U5M	Under-Five Mortality (Rate Per 1000 Live Births)
UNICEF	United Nations Children's Fund
VIF	Variance Inflation Factor
WHO	World Health Organization

Author Contributions

Meissa Diouf: Conceptualization, Methodology
Mbathio Diop: Conceptualization
Ibrahima Gaye: Formal Analysis
Amadou Dieng: Formal Analysis
Morel Aguiar: Data curation
Serigne Ndame Dieng: Writing – original draft
Cheikh Mouhamadou Mbacké Lo: Writing – review & editing
Daouda Faye: Supervision

Data Availability Statement

The data supporting the findings of this study are derived from the Senegal Demographic and Health Surveys and from ANSD official statistics, which are publicly available.

Conflicts of Interest

The authors declare no conflicts of interest.

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