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Assessing Temporal Trends and Ecological Associations Between PM2.5 Exposure, Urbanization, and Under-Five Mortality in Somalia, 1990–2023: An Ecological Time-Series Analysis

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Abstract

Background: Ambient fine particulate matter (PM2.5) is a significant environmental health concern, and rapid urbanization may have an impact on child survival by affecting health-care access, sanitation, housing, poverty, inequality, and environmental exposure. Somalia has a unique situation in which these processes coexist with recurring drought, displacement, violence, and humanitarian disasters.

Objective: To study temporal trends in PM2.5 exposure, urbanization, and under-five mortality in Somalia from 1990 to 2023, as well as to investigate ecological relationships between yearly variations in PM2.5 exposure, urbanization, and under-five mortality.

Methods: This ecological national time-series analysis included 34 yearly observations. Kendall rank tests, Theil-Sen slopes, and linear trend models with heteroskedasticity and autocorrelation (HAC; Newey-West) were used to examine temporal trends. Raw Pearson and Spearman correlations were seen as exploratory. HAC standard errors were used in the main association model to regress first differences in under-five mortality on first differences in PM2.5 and urbanization. Sensitivity and supporting analyzes included robust Huber regression and

influence, as well as residual, autocorrelation, and stationarity tests.

Results: PM2.5 exposure increased over time (Kendall τ=0.387, p=0.001; Theil-Sen slope=0.090 $\mu g/m^3$/year, 95% CI 0.042-0.143), as did urbanization (τ=1.000, p<0.001; slope=0.661 percentage points/year, 95% CI 0.555-0.800), while under-five mortality declined (τ=−0.674, p<0.001; slope=−2.30 deaths per 1,000 live births/year, 95% CI −3.33 to −1.30). Annual variations in PM2.5 (β=1.28, 95% CI −8.81 to 11.36, p=0.804) and urbanization (β=−2.85, 95% CI −25.29 to 19.58, p=0.803) did not substantially impact under-five mortality. Robust sensitivity analysis yielded the same general conclusion.

Conclusion: Long-term increases in PM2.5 exposure and urbanization were associated with lower under-five mortality in Somalia, but year-to-year first-difference analyzes did not replicate the basic ecological trends. These data suggest a careful interpretation of temporal ecological connections but do not show causation.

Keywords: Somalia, PM2.5, under-five mortality, urbanization, ecological research, time series analysis, Newey-West.

1. Introduction.

PM2.5, or tiny particulate matter with an aerodynamic diameter of 2.5 μm or less, poses a significant environmental health concern, especially in low- and middle-income nations such as Sub-Saharan Africa [1, 2]. Children under the age of five are particularly susceptible because of their growing respiratory and immunological systems, increased ventilation relative to body size, and reliance on family and community surroundings. Recent epidemiological studies have shown that greater PM2.5 exposure is associated with worse child survival and related child-health outcomes in various contexts [3, 4, 5, 6, 7].

The evidence for a detrimental connection between ambient PM2.5 and under-five mortality is growing; however, the research remains varied. A multi-country study in South Asia and Sub-Saharan Africa found that greater PM2.5 exposure was associated with a higher risk of infant death, although the correlations varied with time [3]. In Ethiopia, higher lifetime annual mean PM2.5 exposure researchers found that higher lifetime annual mean PM2.5 exposure correlates with an increased risk of under-five mortality [4]. A scoping review, however, found that little research has explicitly investigated long-term post-birth ambient PM2.5 exposure and under-five mortality, emphasizing ongoing data gaps [8].

The link between PM2.5 and child health is unlikely to be consistent across contexts due to

variations in particle composition, concentration range, exposure time, source profile, and geographic scale. In low- and middle-income countries, wind-blown dust PM2.5 has been linked to an increased risk of under-five mortality and a nonlinear exposure-response function [9]. In Sub-Saharan Africa, the relationship between ambient PM2.5 and child undernutrition varies both within and across countries [10]. Africa has a particular pollution profile, with significant contributions from windblown dust, biomass burning, domestic solid-fuel combustion, and other sources [11]. As a result, national yearly averages may obscure significant variations in concentration and toxicity at the local level.

Another important demographic change that has an impact on child survival is urbanization. Historically, urban living in many African contexts In many African contexts, urban living historically has improved access to health care, infrastructure, sanitation, education, and markets. More recent data, however, reveals that the urban survival advantage has shrunk in certain situations due to informal urban expansion, overcrowding, poverty, insufficient amenities, and rising intra-urban inequality [12]. Urbanization should not be understood as intrinsically protective; rather, it might reflect a complicated structural process that influences health-care access, environmental conditions, housing quality, socioeconomic opportunity, and inequality [12, 13].

Somalia is an excellent place to investigate these long-term tendencies. Recurrent droughts, armed conflict, relocation, diseases, food shortages, and humanitarian crises have had a significant impact on population mortality and community geographic dispersion [14]. At the same time, national environmental and demographic indices have shifted significantly. These overlapping trends make interpretation difficult since two variables that move regularly in different directions over time might look highly connected even if their year-to-year variations are unrelated. Other studies have shown that accounting for long-term temporal structure may significantly affect pollution-mortality estimates [15, 16].

While national ecological time-series data cannot detect individual-level impacts, they can capture long-term changes and determine whether yearly co-movements persist after eliminating common trends. This difference is especially important in data-limited and unstable environments, where lengthy national series may be accessible before regularly recorded subnational individual-level data. As a result, this research analyzed temporal patterns in PM2.5 exposure, urbanization, and under-five mortality in Somalia from 1990 to 2023, and whether

year-to-year variations in PM2.5 exposure and urbanization were environmentally related to year-to-year changes in under-five death.

2. Materials & Methods

2.1 Study Design and Data Sources

An ecological annual time-series analysis for Somalia was undertaken utilizing 34 yearly measurements from 1990 to 2023. Three indicators were gathered from the World Bank World Development Indicators (WDI) [17]: PM2.5 air pollution, mean annual exposure (indicator EN.ATM.PM25.MC.M3), urban population (% of total population (indicator SP.URB.TOTL.IN.ZS), and mortality rate under five (indicator SH.DYN.MORT). The PM2.5 indicator assesses population-weighted yearly exposure to ambient particles with an aerodynamic diameter below 2.5 μm, based on Global Burden of Disease 2023 projections. Urban population estimates are based on the United Nations World Urbanization Prospects and national definitions of urban regions. The United Nations Inter-agency Group for Child Mortality Estimation (UN IGME) calculates under-five mortality as the likelihood of dying before the age of five for every 1,000 live births.

2.2 Study variables

The outcome variable was the under-five mortality rate (U5MR), which is reported as deaths per 1,000 live births. The main explanatory factors were yearly mean PM2.5 exposure (μg/m³) and the proportion of the population residing in cities. Calendar year was utilized to represent secular trends, but it was not included with urbanization in the principal association model since the two data were closely correlated across time.

2.3 Data Preparation and Quality Assessment

The dataset was sorted chronologically, and all analytic variables were transformed to numerical values. Before analyzing, we verified for completeness, duplicated years, and implausible data. There were no missing observations or duplicated years. High under-five death rates between the early 1990s and 2011 were kept since they were part of the source series; they were handled as potentially important data rather than being immediately eliminated. The first difference was determined as the value in year t minus the value in year t-1 for PM2.5, urbanization, and

U5MR. As a result, 33 observations were included in the year-to-year change analyzes.

2.4 Statistical Analysis

Continuous variables were summarized using the mean, SD, median, IQR, minimum, and maximum. Long-term temporal trends were evaluated using Kendall's rank correlation with the calendar year and the Theil-Sen median slope, which give reliable non-parametric estimates of monotonic change. To ensure consistency with traditional yearly trend estimates, ordinary least-squares trend models with heteroskedasticity- and autocorrelation-consistent (HAC; Newey-West) standard errors were fitted with a maximum latency of two years.

Pearson and Spearman correlation coefficients were used to assess unadjusted level relationships between PM2.5, urbanization, and U5MR; these analyzes were deemed exploratory due to the possibility of misleading level correlations resulting from trending time series. The major association analysis employed first differences to fit ΔU5MR as a function of ΔPM2.5 and Δurbanization, using HAC standard errors and a one-year maximum latency. This specification determines if year-to-year changes in exposures correlated with year-to-year changes in mortality after adjusting for common long-run trends. A Huber M-estimator robust regression was employed as a sensitivity study to lessen the impact of particularly high yearly mortality shocks while not eliminating those years. A secondary-level model with PM2.5 and urbanization was preserved only for descriptive purposes.

Variance inflation factors (VIFs), Cook's distance, residual-versus-fitted plots, Q-Q plots, the Durbin-Watson statistic, the Breusch-Pagan test, and Ljung-Box tests were all used to diagnose the model. A diagnostic model using a calendar year showed significant collinearity between urbanization and time (VIFs >10), hence it was not employed as the main inferential model. Because of the short series and low- test power, augmented Dickey-Fuller (ADF) tests were utilized as supplementary checks rather than as the only model selection criterion. The ADF findings were varied, including the inability to reject a unit root for first-differenced urbanization, and should thus be treated with caution. All tests were two-sided, and $p<0.05$ indicated statistical significance. Python was used for the analyzes, using pandas, SciPy, stats models, and Matplotlib.

3. Results

3.1 Descriptive characteristics and temporal patterns

The analysis included 34 annual observations from 1990 through 2023. Mean PM2.5 exposure was 17.88 µg/m³ (SD 1.75), with values ranging from 11.97 to 21.11 µg/m³. The mean proportion of the population living in urban areas was 38.76% (SD 7.99), increasing from 29.40% to 54.07% during the study period. Mean U5MR was 182.59 per 1,000 live births (SD 72.50), with a median of 173.20 and a range of 104.30–376.60 per 1,000 live births (Table 1).

Table 1. Descriptive statistics for the study variables, Somalia, 1990–2023

Variable	Mean	SD	Median	IQR	Minimum	Maximum
PM2.5 (µg/m³)	17.88	1.75	17.97	1.56	11.97	21.11
Urban population (%)	38.76	7.99	36.28	11.17	29.40	54.07
Under-five mortality (per 1,000)	182.59	72.50	173.20	30.08	104.30	376.60

PM2.5 exposure fluctuated substantially across years but showed an overall upward pattern, with a marked low in 1995 and several peaks above 20 µg/m³ (Figure 1).

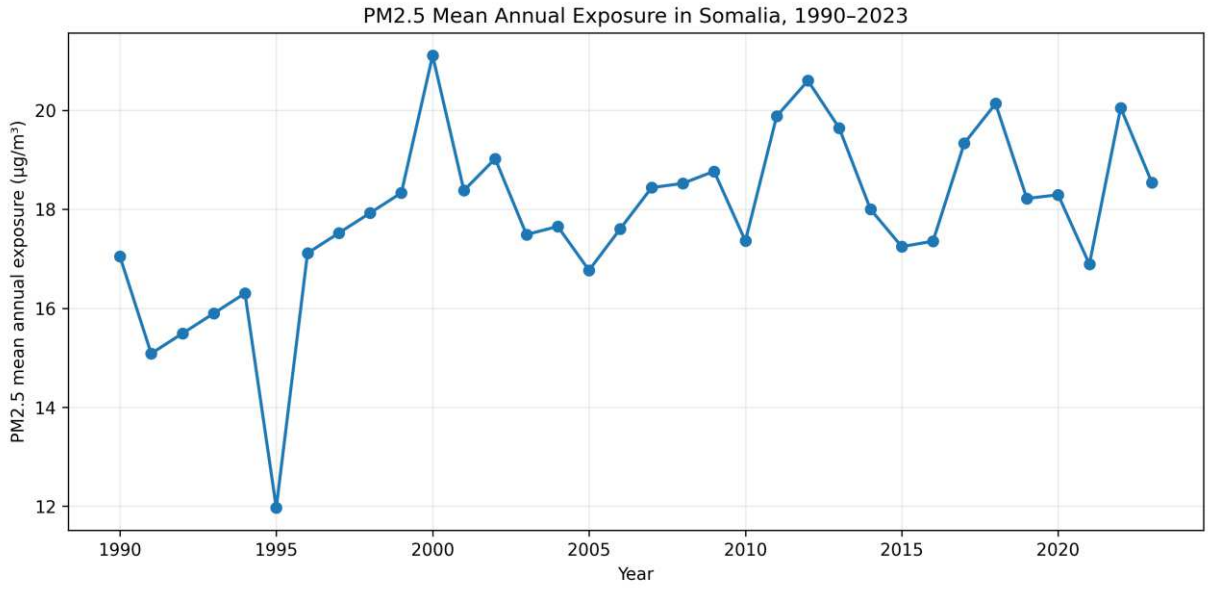


Figure 1. Annual mean PM2.5 exposure in Somalia, 1990–2023.

Urbanization increased continuously across the full observation period, with a visibly faster rise during the mid-to-late 2010s (Figure 2).

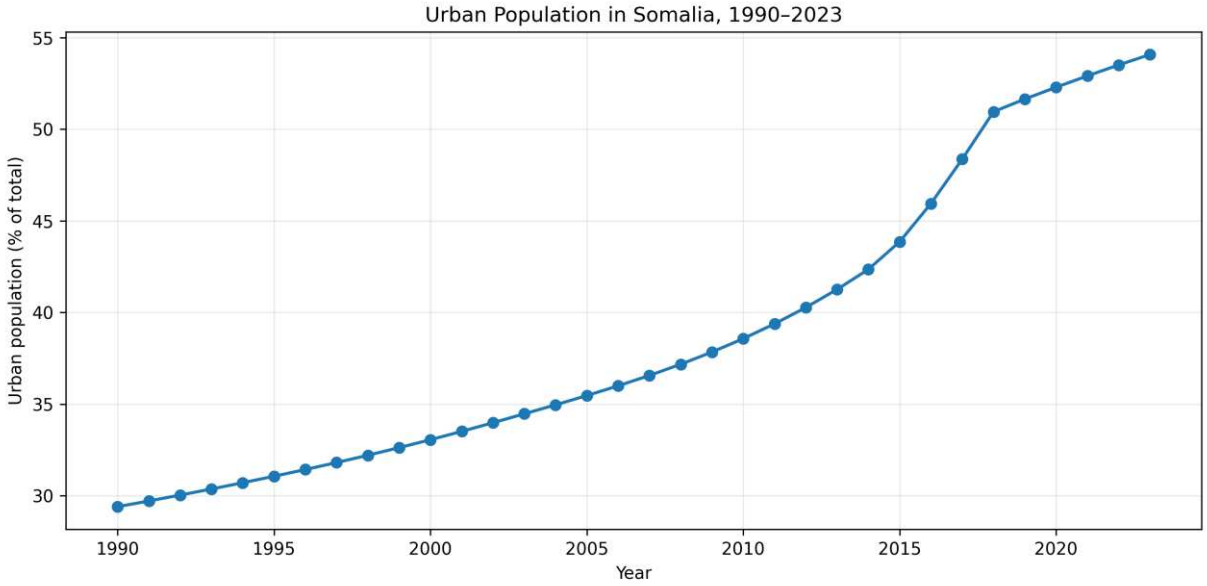


Figure 2. Urban population as a percentage of the total population in Somalia, 1990–2023.

Under-five mortality displayed a long-run decline but included pronounced mortality peaks in the early 1990s and in 2011 (Figure 3). These observations were retained in all main analyses and addressed through robust and influence-sensitive procedures rather than deletion.

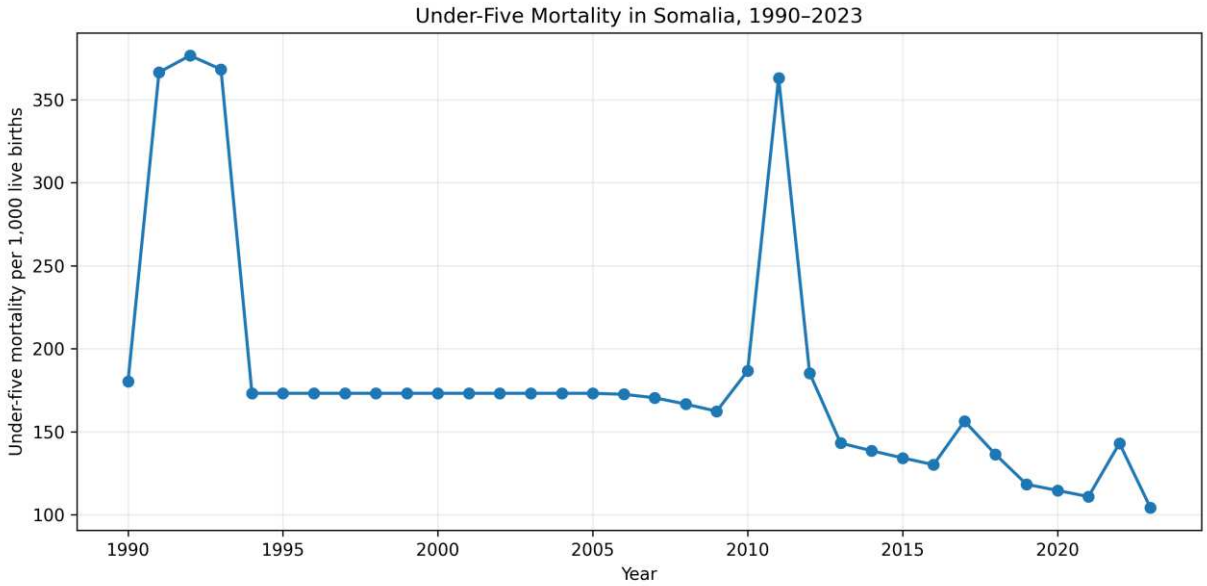


Figure 3. Under-five mortality rate in Somalia, 1990–2023.

Standardized series further illustrated the divergent long-run trajectories: urbanization generally increased, under-five mortality generally declined, and PM2.5 showed a weaker but positive long-run tendency (Figure 4).

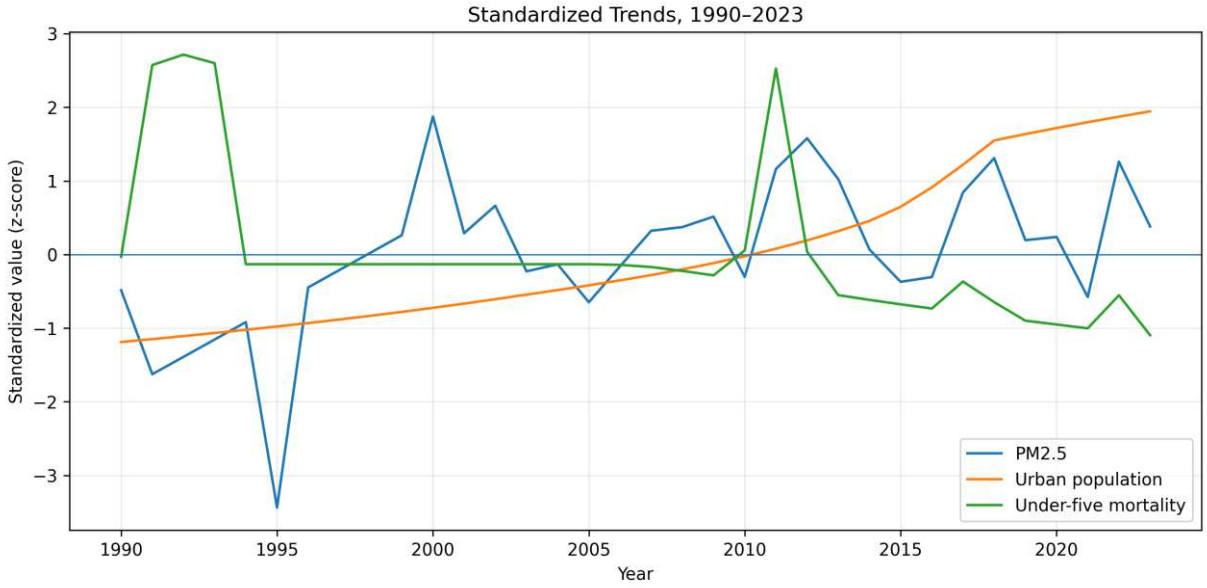


Figure 4. Standardized temporal trends in PM2.5 exposure, urbanization, and under-five mortality, 1990–2023.

3.2 Long-term temporal trends

Robust trend analysis confirmed statistically significant changes in all three series (Table 2). PM2.5 exposure increased over time (Kendall τ=0.387, p=0.001), with a Theil–Sen slope of 0.090 µg/m³ per year (95% CI 0.042–0.143). The HAC linear trend estimate was similar at 0.091 µg/m³ per year (p=0.002). Urbanization showed a strictly monotonic increase (τ=1.000, p<0.001), with a Theil–Sen slope of 0.661 percentage points per year (95% CI 0.555–0.800) and an HAC linear slope of 0.769 percentage points per year (p<0.001). In contrast, U5MR declined significantly (τ=−0.674, p<0.001); the Theil–Sen slope indicated a median decline of 2.30 deaths per 1,000 live births per year (95% CI −3.33 to −1.30), while the HAC linear estimate indicated an average decline of 4.14 per 1,000 live births per year (p=0.003).

Table 2. Robust and HAC estimates of long-term temporal trends, 1990–2023

Variable	Kendall τ	p-value	Theil–Sen slope/year	95% CI	HAC slope/year	HAC p-value
PM2.5	0.387	0.001	0.090	0.042 to 0.143	0.091	0.002
Urban population	1.000	<0.001	0.661	0.555 to 0.800	0.769	<0.001
Under-five mortality	−0.674	<0.001	−2.300	−3.333 to −1.300	−4.138	0.003

3.3 Ecological associations with under-five mortality

At the level of the original annual series, PM2.5 was weakly and inversely correlated with U5MR, but the association was not statistically significant (Pearson r=−0.296, p=0.089; Spearman ρ=−0.300, p=0.085). Urbanization showed a stronger inverse level correlation with U5MR (Pearson r=−0.537, p=0.001; Spearman ρ=−0.798, p<0.001). Because urbanization increased while mortality declined over the same calendar period, these level correlations were treated as descriptive rather than causal evidence. Correlations based on first differences were weak and not statistically significant (Table 3).

Table 3. Exploratory level and first-difference correlations with under-five mortality

Scale	Predictor	Pearson r	Pearson p	Spearman ρ	Spearman p
Levels	PM2.5	−0.296	0.089	−0.300	0.085
Levels	Urban population	−0.537	0.001	−0.798	<0.001
First differences	ΔPM2.5	0.032	0.858	0.175	0.329
First differences	ΔUrban population	−0.021	0.907	−0.330	0.060

In the primary first-difference HAC model, year-to-year change in PM2.5 was not associated with year-to-year change in U5MR (β=1.28, 95% CI −8.81 to 11.36, p=0.804). Likewise, annual change in urbanization was not significantly associated with annual change in U5MR (β=−2.85, 95% CI −25.29 to 19.58, p=0.803). The model explained little of the annual variation in mortality change (R^2=0.002). These findings indicate that the strong inverse level association between urbanization and mortality was not reproduced when the shared long-term time trend was reduced through differencing.

[Insert Table 4 here]

Table 4. Primary first-difference model and robust sensitivity analysis

Model	Predictor	β	95% CI	p-value	Interpretation
Primary first-difference HAC	ΔPM2.5	1.279	−8.805 to 11.364	0.804	Not significant
Primary first-difference HAC	ΔUrban population	−2.854	−25.292 to 19.583	0.803	Not significant
Robust Huber sensitivity	ΔPM2.5	0.515	−0.655 to 1.686	0.388	Not significant
Robust Huber sensitivity	ΔUrban population	−3.627	−7.296 to 0.043	0.053	Not significant at 0.05

The first-difference scatterplots similarly showed little evidence of a strong linear year-to-year relationship between changes in either exposure and changes in U5MR (Figures 5 and 6).

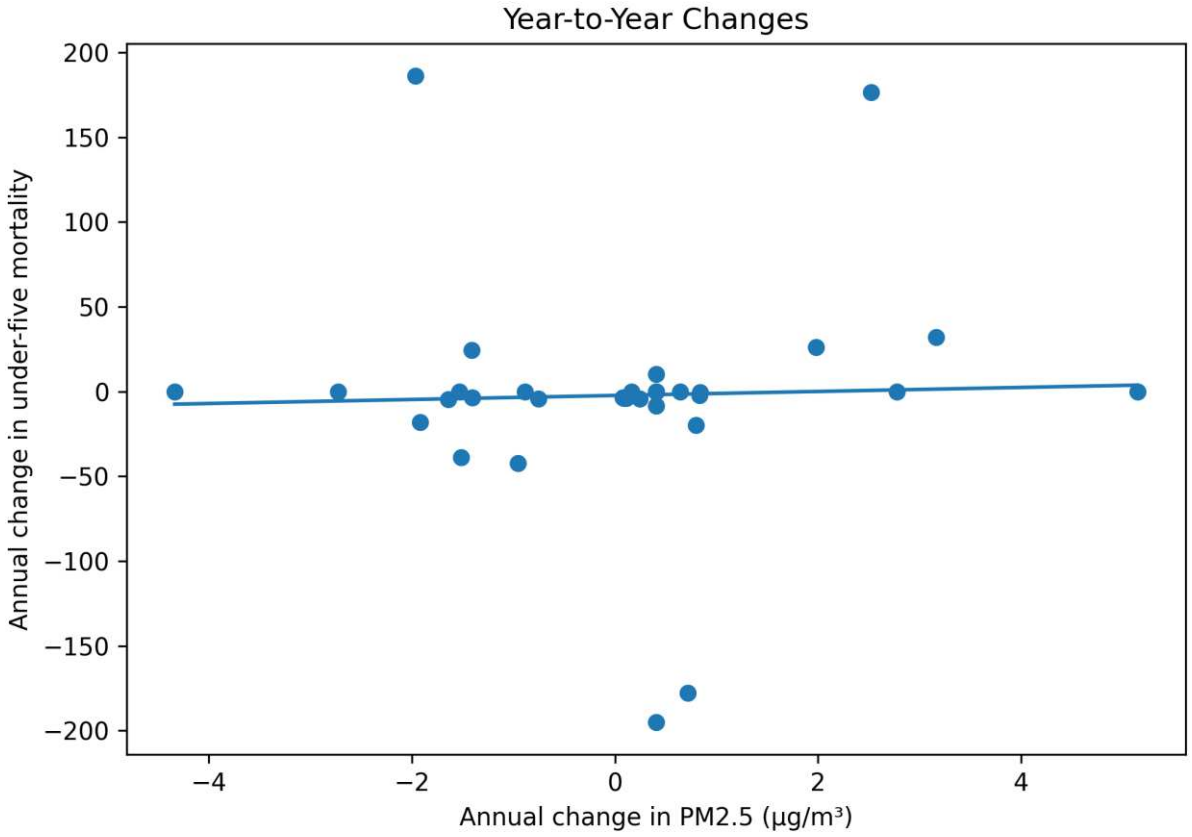


Figure 5. Annual change in PM2.5 exposure versus annual change in under-five mortality.

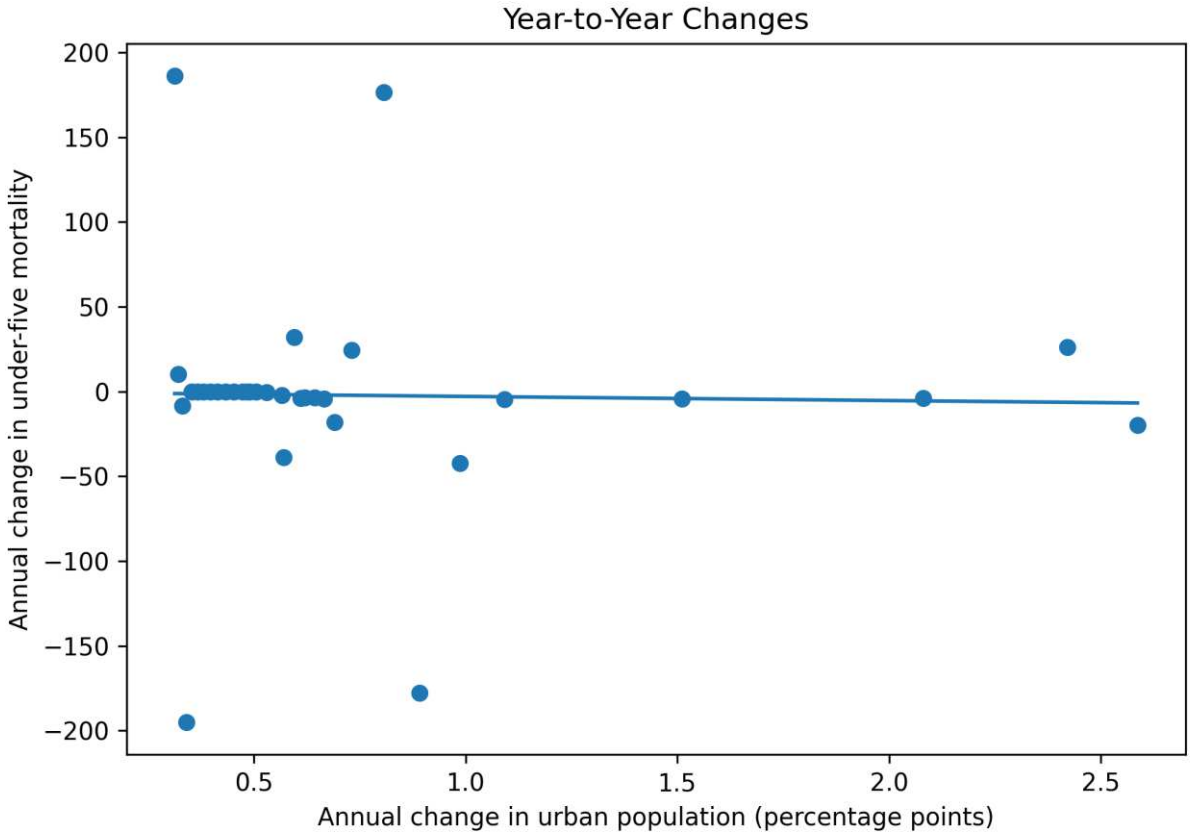


Figure 6. Annual change in urban population share versus annual change in under-five mortality.

3.4 Sensitivity and diagnostic analyses

The robust Huber first-difference model produced the same overall interpretation as the primary HAC model. The coefficient for annual PM2.5 change remained non-significant (β=0.52, 95% CI −0.66 to 1.69, p=0.388). The coefficient for annual urbanization change was negative and approached, but did not reach, the conventional 0.05 significance threshold (β=−3.63, 95% CI −7.30 to 0.04, p=0.053). Accordingly, this sensitivity result was interpreted as suggestive rather than statistically significant.

A secondary level model with HAC standard errors showed a negative urbanization coefficient, but this specification remained vulnerable to secular-trend confounding. When calendar year was added for diagnostic purposes, urbanization and year showed high multicollinearity (VIF=13.68 and 15.39, respectively), whereas the VIF for PM2.5 was 1.51. The time-adjusted coefficients were not statistically significant. Cook's distance identified 1991, 1992, 1993, 1995, and 2011 as influential years using the 4/n threshold; these observations were retained

because they belonged to the source series and could represent substantively important periods rather than data errors.

Residual diagnostics for the secondary level OLS model showed a Durbin–Watson statistic of 1.18. Breusch–Pagan tests did not indicate strong heteroskedasticity (LM p=0.222; F p=0.238), whereas Ljung–Box tests indicated residual serial correlation at lags 1–3 ($p \leq 0.050$), supporting the use of HAC standard errors rather than conventional OLS inference. ADF results were mixed: first-differenced PM2.5 and U5MR rejected a unit root, whereas first-differenced urbanization did not. Given the short series, ADF tests were treated as supporting diagnostics rather than definitive evidence of stationarity.

[Insert Table 5 here]

Table 5. Selected diagnostic findings

Diagnostic	Result	Interpretive role
VIF: PM2.5	1.51	Low multicollinearity
VIF: urbanization	13.68	High collinearity with time
VIF: calendar year	15.39	High collinearity with urbanization
Durbin–Watson	1.18	Suggests positive residual dependence
Breusch–Pagan LM p-value	0.222	No strong heteroskedasticity signal
Ljung–Box lag 1 p-value	0.014	Residual serial correlation in level OLS
Influential years	1991, 1992, 1993, 1995, 2011	Retained; assessed via robust/influence diagnostics
ADF, Δurbanization	p=0.988	Unit-root null not rejected; interpret differenced model cautiously

Overall, Somalia experienced significant long-term increases in PM2.5 exposure and urbanization alongside a significant decline in under-five mortality between 1990 and 2023.

However, after focusing on year-to-year changes to reduce the influence of common secular trends, neither PM2.5 change nor urbanization change showed a statistically significant independent association with annual changes in under-five mortality.

4. Discussion

Our ecological national time-series study for the period 1990 to 2023 identified three distinct long- term trends in Somalia: an increase in PM2.5 exposure, a large increase in the urban population and a decrease in under-five death rates. Correlations at the crude level revealed negative correlation especially between urbanization and under-five mortality. However, considering year-over-year changes, the level relationships did not replicate with the first-difference HAC regression. The distinction between strong level trends and weak yearly co-movement is significant because time-series variables that move consistently over a calendar year might look connected even while short-term changes are unrelated. The data therefore support a descriptive reading of the long-term trajectories rather than a causative interpretation of the crude correlations [15, 3].

The result that PM2.5 levels rose while under-five mortality declined does not contradict the larger literature on the negative impact of air pollution on child health. Several recent studies have shown negative relationships between PM2.5 exposure and under-five mortality or associated outcomes, such as child survival, stunting, anemia, and other indicators of susceptibility [3, 4, 5, 10, 7, 18]. A comprehensive review and meta-analysis found that air pollution is linked to illness and death in children under the age of five in Sub-Saharan Africa, but it also highlighted persisting data gaps [19]. The nil year-to-year correlation in the current research should be taken as a characteristic of this national ecological series and analytic scale, rather than proof that PM2.5 is physiologically innocuous.

Several factors might explain why the crude long-run connection diminished after temporal correction. First, the impact of PM2.5 may vary depending on the period of exposure. Amir-Ud-Din et al. [3] found period-specific variances in the PM2.5-child mortality link, suggesting that a single average yearly association may mask temporal variability. Second, source composition is important. Wind-blown dust PM2.5 has been linked to increased under-five mortality in low- and middle-income nations, with indications of nonlinearity [9]. Third, Africa's ambient PM2.5 mixture includes dust, biomass burning, domestic fuel combustion, and other sources that may have diverse toxicological characteristics [11]. A national yearly mean cannot discriminate

between source-specific exposures and much greater concentrations that may occur in some localities.

Exposure assessment also restricts inference. Population-weighted national PM2.5 models are beneficial for broad comparisons, but they may obscure short-term peaks, local combustion sources, urban-rural variations, and geographical variability. Recent research in Sub-Saharan Africa indicates that the relationship between PM2.5 and child outcomes varies widely [10]. If the biologically relevant exposure fluctuates on smaller regional or temporal scales than the yearly national series, measurement error will likely weaken connections. Another option is that yearly variations in exposure have a delayed impact on child health, which a contemporaneous first-difference model does not account for. The short amount of yearly data made it difficult to fit complicated nonlinear or distributed-lag models without significantly increasing the risk of overfitting.

The urbanization results need comparable care. The high negative raw connection between urban population share and U5MR roughly corresponds to the historical urban survival advantage documented in Sub-Saharan Africa. However, recent data suggests that this benefit has dwindled in many contexts, since rapid informal urban expansion, impoverishment, congestion, and intra-urban inequality may all counteract improvements in service access [12]. Urbanization is not a health intervention; rather, it is a demographic and structural process with health consequences that are determined by housing, sanitation, health-care access, education, income, environmental quality, and social inequality [12, 13].

This difference is especially crucial in Somalia. Rising urban population share may represent relocation to towns and cities due to drought, instability, and livelihood disruption, rather than a systematically planned growth of urban services [14]. Consequently, a larger urban population may coexist with severe deprivation for some groups and increased access for others. The robust estimate only approached the conventional significance level, and the first-difference findings revealed no statistically significant relationship between annual urbanization changes and yearly U5MR fluctuations. These findings do not determine whether urbanization has a positive or negative effect; rather, they demonstrate that the fundamental long-term inverse trend is insufficient for causal examination. Neglecting time-varying confounding poses a significant challenge. The mortality rates in Somalia have been influenced by various factors, including conflict, drought, famine, disease, displacement, and humanitarian crises. These mechanisms

may directly affect mortality rates among children under five, in conjunction with urbanization, environmental contamination, economic participation, and healthcare accessibility. Vaccination rates, maternal education, fertility, family income, public health spending, water and sanitation, nutrition, prevalence of infectious diseases, temperature, humidity, and humanitarian aid are additional potential factors. Investigations throughout Africa have demonstrated that socioeconomic elements, household environmental hazards, and health-system factors are critical determinants of child survival and vulnerability to environmental health challenges. The existing correlations are vulnerable to residual confounding because these factors were not uniformly available in the same annual national datasets.

The impact study also demonstrates why extreme years should not be removed only because they are statistically rare. The early 1990s and 2011 had very high death rates and were important in level models. In a vulnerable environment, such figures may reflect actual moments of crisis rather than data mistakes. Retaining them while using robust regression, HAC inference, and impact diagnostics maintains meaningful information and provides a more defensible sensitivity framework than automated outlier removal. The persisting serial correlation in the level OLS residuals supported the use of HAC standard errors and reaffirmed the choice to avoid conventional level OLS inference.

The study's main contribution is methodological as well as descriptive. It examines long-term national patterns in an understudied context and shows that crude ecological correlations may vary significantly from analyzes based on yearly variations. This is in line with broader evidence that structure of the trend, temporal variability and magnitude of exposure are important for pollution-health estimates [15, 16]. Future research should include subnational PM2.5 estimations, population relocation, conflict intensity, climatic anomalies, health-care indicators, and child outcomes. Higher temporal precision and explicit lag structures would be especially useful in separating acute environmental shocks from delayed structural changes.

5. Strengths and Limitations.

This research has various merits. It provides a 34-year national series for Somalia, where long-term environmental-health analyses are sparse. The study explicitly distinguished between descriptive trend estimation and association modeling, using non-parametric Theil-Sen and Kendall approaches, alongside HAC trend estimations, viewed raw level correlations as exploratory rather than causative.

First we differenced the data to reduce the impact of common secular trends and used HAC standard errors to address common secular trends. HAC standard errors addressed serial dependency. Influential crisis years were kept and evaluated with Cook's distance and robust Huber regression instead of being discarded unless there is evidence of data inaccuracy. These options enhance the transparency and reduce the possibility of overinterpreting the relationships at the standard level. There are significant constraints. First, the ecological design is prone to ecological fallacy and cannot infer at the individual level. Second, the length of the data series (34 years only) decreased the statistical power and reliability of complex time series models. Third, national averages obscure significant subnational, urban-rural, and intra-urban variation in exposure and child health [10]. Fourth, predicted PM2.5 estimates may not account for area peaks, source composition, or individual exposure, while fatality predictions are likewise questionable. Fifth, time-varying confounding from violence, drought, displacement, health services, immunization, sanitation, nutrition, poverty, and epidemics could not be completely controlled. Sixth, initial differencing decreases common long-run trends while increasing measurement noise and shifting the estimand toward short-term yearly co-movement, perhaps ignoring slower cumulative or delayed correlations. Supporting ADF tests had limited power in this short series and yielded conflicting findings; for example, the first-differenced urbanization series did not reject a unit root. Seventh, the study did not adequately address nonlinear exposure response functions, distributed delays, or structural discontinuities. Finally, severe shocks in a fragile environment might result in sudden changes that are not adequately captured by a single national yearly model. The results should be seen as descriptive and hypothesis-generating rather than causative estimates of the impact of PM2.5 or urbanization on child mortality.

6. Conclusion.

In Somalia, we found a strong long-term increase in PM2.5 exposure and urbanization, and a significant decline in under-five mortality between 1990 and 2023. Crude yearly level correlations suggested a negative association between urbanization and child mortality, but these patterns did not hold when the research focused on year-to-year variation. In the main first-difference HAC model, neither annual PM2.5 change nor annual urbanization change was substantially linked with yearly change in under-five mortality, and rigorous sensitivity analysis revealed the same general conclusion. These results suggest distinguishing between common historical patterns and ecological associations and should not be construed as proof that PM2.5 is harmless or that

urbanization is intrinsically protective. Future research should combine subnational and individual-level findings with higher-resolution pollution estimates, conflict and displacement data, climatic shocks, health-care indicators, and explicit lag structures. Continued air-quality monitoring and child-health surveillance are critical in fast-changing and vulnerable environments such as Somalia.

Author contributions

Omar Aweis Ali: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, and Supervision.

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All authors contributed to the interpretation of the findings, critically reviewed the manuscript for important intellectual content, approved the final version of the manuscript, and agreed to be accountable for all aspects of the work.

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Not applicable.

Competing Interests

The authors declare that there are no competing interests.

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Declarations

Ethics Approval

Not applicable.

Consent to Participate

Not applicable.

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Not applicable.

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