



Sanitation Access and Child Survival: A 24-Year Global Panel Analysis, 2000–2023

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Abstract

Access to adequate sanitation remains an important environmental determinant of child survival, although its independent contribution is difficult to distinguish from improvements in drinking water and broader socioeconomic development. This study examined the relationship between basic sanitation access and child mortality across countries from 2000 to 2023 using World Development Indicators data. The analysis employed a longitudinal country-level panel comprising 4,287 country-year observations from 185 countries and economies, with a balanced-panel subsample of 155 countries. Under-five mortality was the primary outcome, while infant and neonatal mortality were examined as additional outcomes. Two-way fixed-effects regressions controlled for basic drinking-water access, GDP per capita, health expenditure, urbanization, country-specific characteristics, and common year effects, with standard errors clustered by country. Basic sanitation was strongly associated with lower under-five mortality when drinking-water access was excluded from the model ($\beta = -0.775$, $p < .001$). After water access was included, the sanitation coefficient declined to $\beta = -0.288$ ($p = .070$), indicating substantial overlap between sanitation and the broader WASH environment. Nevertheless, sanitation remained significantly associated with lower infant mortality ($\beta = -0.231$, $p = .006$) and neonatal mortality ($\beta = -0.159$, $p < .001$). In the balanced panel, sanitation was again significantly associated with under-five mortality ($\beta = -0.409$, $p = .034$). Safely managed sanitation did not exhibit an additional independent association with under-five mortality in the fully adjusted model. The findings indicate that sanitation contributes to child survival but operates within an interconnected system of water access and socioeconomic development. Policies aimed at reducing child mortality should therefore emphasize integrated WASH improvements rather than sanitation infrastructure in isolation.

Keywords: *sanitation access; child mortality; under-five mortality; infant mortality; neonatal mortality; WASH; panel data; World Development Indicators*

1. Introduction

Child survival has improved substantially over the past several decades, yet preventable mortality among children remains a major global public-health concern. In 2024, an estimated 4.9 million children died before reaching five years of age, including approximately 2.3 million during the neonatal period. The pace of reduction has also slowed since 2015, indicating that earlier gains cannot be assumed to continue automatically (United Nations Inter-agency Group for Child Mortality Estimation [UN IGME], 2026). The persistence of child mortality reflects multiple interacting determinants, including poverty, nutrition, maternal health, healthcare access, environmental exposure, drinking-water quality, and sanitation conditions.

Sanitation represents one of the most fundamental environmental determinants of child health. Inadequate disposal and management of human waste increase exposure to pathogenic organisms through contaminated water, food, soil, household environments, and person-to-person transmission. These exposures are particularly consequential during infancy and early childhood, when repeated infections can interact with malnutrition, dehydration, and limited healthcare access. Poor sanitation is linked to diarrhoeal diseases, cholera, dysentery, typhoid, intestinal worm infections, and other conditions that disproportionately affect young children (World Health Organization [WHO], 2024b).

Diarrhoeal disease illustrates this relationship particularly clearly. It remains a major cause of death among young children and is responsible for approximately 443,832 deaths among children under five each year. A substantial proportion of diarrhoeal disease can be prevented through safe drinking water, adequate sanitation, and appropriate hygiene (WHO, 2024a). Beyond immediate mortality, repeated diarrhoeal infection can contribute to malnutrition, which in turn increases susceptibility to subsequent illness. Sanitation can therefore influence child survival through both direct disease-prevention pathways and longer-term interactions involving nutrition, growth, and resilience to infection.

Despite its public-health importance, universal sanitation remains far from achieved. Global safely managed sanitation coverage increased from 48% in 2015 to 58% in 2024, yet approximately 3.4 billion people still lacked safely managed sanitation services in 2024 (World Health Organization & United Nations Children's Fund [WHO & UNICEF], 2025). Inequalities remain substantial across income groups, rural and urban areas, fragile settings, and geographic regions. These disparities are especially relevant to child health because countries and communities with

weak sanitation infrastructure frequently face overlapping disadvantages in income, healthcare access, nutrition, education, and water security.

This overlap presents an important analytical problem. Countries that improve sanitation typically improve other dimensions of development at the same time. Drinking-water access tends to expand together with sanitation infrastructure, while income growth can increase both household access to improved facilities and government capacity to finance public-health services. Urbanization may facilitate centralized water and sanitation systems but may also create densely populated settlements where inadequate infrastructure generates concentrated environmental risks. Health expenditure, primary healthcare expansion, immunization, maternal education, and improved nutrition may likewise reduce child mortality during the same period that sanitation coverage increases.

Consequently, a strong negative correlation between sanitation coverage and child mortality does not necessarily indicate that sanitation alone accounts for the observed difference. A country with near-universal sanitation is also likely to differ from a country with limited sanitation in numerous socioeconomic and institutional characteristics. Even within the same country, improvements in sanitation may coincide with improvements in drinking water, household income, health services, and urban infrastructure. Determining the independent association of sanitation with child survival therefore requires analytical designs that account for these accompanying changes.

The relationship between sanitation and drinking water is particularly important. Both are core components of water, sanitation, and hygiene (WASH), and their health effects are closely interconnected. Improved sanitation reduces environmental contamination, while safe drinking water reduces exposure through consumption. Global burden estimates and intervention reviews indicate that unsafe WASH remains a substantial contributor to diarrhoeal disease and other adverse health outcomes (Sharma Waddington et al., 2023; Wolf et al., 2023). At the same time, the high degree of overlap between water and sanitation development makes their independent statistical contributions difficult to separate.

A longitudinal cross-country approach provides one means of addressing these issues. Panel data allow researchers to examine not only whether countries with higher sanitation coverage have lower child mortality, but also whether improvements in sanitation within the same country over time are associated with reductions in mortality. Country fixed effects can account for relatively stable national characteristics, while year fixed effects can account for global influences shared across countries. Including drinking-water access, income, health expenditure, and urbanization provides an additional means of distinguishing sanitation from accompanying dimensions of development (Wooldridge, 2010).

Child mortality itself can also be examined at several stages of early life. Under-five mortality provides a broad measure of survival during the first five years, while infant mortality captures deaths before the first birthday and neonatal mortality focuses on the first 28 days of life. Sanitation may not influence these outcomes equally. Environmental exposure and enteric infections become increasingly relevant as infants interact with household surroundings, food, and water, whereas neonatal mortality is also strongly determined by pregnancy, delivery, prematurity, congenital conditions, and immediate postnatal care.

Against this background, the present study examines the relationship between basic sanitation access and child mortality across countries from 2000 to 2023 using World Development Indicators data (World Bank, n.d.). Under-five mortality serves as the principal child-survival outcome, while infant and neonatal mortality are examined as additional outcomes. Basic drinking-water access is incorporated explicitly to distinguish the sanitation relationship from the wider WASH environment, together with controls for economic development, health expenditure, and urbanization.

The study addresses five objectives: (1) to describe changes in basic sanitation access and child mortality across countries from 2000 to 2023; (2) to determine the association between basic sanitation coverage and under-five mortality; (3) to assess whether this association persists after accounting for drinking-water access, economic development, health expenditure, urbanization, country-specific characteristics, and common time effects; (4) to examine whether sanitation exhibits comparable relationships with infant and neonatal mortality; and (5) to evaluate the robustness of the relationship across alternative panel specifications.

By distinguishing sanitation from related WASH and socioeconomic conditions, the study seeks to move beyond the simple observation that countries with better sanitation generally experience lower child mortality. Instead, it examines whether improvements in sanitation remain associated with improved child survival when countries are compared with their own historical trajectories and when broader developmental changes are taken into account. In doing so, the study positions sanitation as one component of an interconnected public-health environment whose contribution to child survival must be understood in relation to water access, socioeconomic development, and health-system capacity.

2. Review of Related Literature

2.1 Sanitation Access and Under-Five Mortality

A consistent body of evidence links improved sanitation access with lower under-five mortality. Studies across low- and middle-income countries show that inadequate sanitation increases children's exposure to fecal pathogens, diarrhoeal disease, and chronic enteric infections, while improved sanitation reduces these pathways of exposure. Multicountry analyses in sub-Saharan Africa and South Asia report higher mortality among children living in households without improved sanitation facilities (Gaffan et al., 2023; Ly et al., 2022). A global spatiotemporal

analysis likewise identified basic sanitation as an important development indicator associated with lower under-five mortality (Amegbor & Addae, 2023).

The relationship is also supported by longitudinal and quasi-experimental evidence. In India, district-level expansion of toilet construction under the Swachh Bharat Mission was associated with lower infant and child mortality, while national time-series evidence from Sudan similarly linked WASH expansion with reductions in under-five mortality (Chakrabarti et al., 2024; Mohamed, 2024). These findings are consistent with the view that population-level sanitation expansion can generate measurable survival gains when coverage becomes sufficiently broad.

The principal mechanism is interruption of fecal-oral transmission. Improved sanitation reduces exposure to pathogens responsible for diarrhoea and related infectious diseases, which remain major contributors to child morbidity and mortality. Sanitation may also affect survival indirectly through nutritional pathways because repeated enteric infections impair nutrient absorption and can contribute to stunting and wasting (Merid et al., 2023; Soe et al., 2023; Wolf et al., 2022). Child nutrition outcomes such as stunting have also been examined alongside macroeconomic and labor indicators in ASEAN economies using World Development Indicators data, with country-specific patterns differing across economies (Quinto & Atento, 2025). However, the magnitude of the mortality relationship varies across socioeconomic and health-system contexts, indicating that sanitation is an important determinant of under-five survival but is embedded within a wider public-health environment.

2.2 Sanitation and Early-Life Mortality

Improved sanitation is also associated with lower infant and neonatal mortality, although the mechanisms differ across stages of early childhood. The protective effect appears particularly strong for infant and post-neonatal mortality because children become increasingly exposed to household environments, contaminated surfaces, food, and water during the first year of life (Ly et al., 2022).

Evidence from large-scale national programs illustrates this relationship. Chakrabarti et al. (2024), examining India's Swachh Bharat Mission across 640 districts, reported measurable declines in infant mortality associated with substantial toilet construction. Multicountry reviews likewise suggest that community-wide sanitation coverage can reduce childhood mortality more effectively than isolated household improvements (Sharma Waddington et al., 2023).

The relationship with neonatal mortality is also evident but appears more dependent on community-level sanitation and maternal health conditions. Kmush et al. (2021), using pooled survey data covering approximately 1.25 million live births, found lower neonatal mortality among women living in communities with high sanitation coverage. Kamal and Shakeel (2021) likewise reported reduced neonatal mortality among households with improved toilet facilities in Pakistan. The mechanisms in the neonatal period may include reduced maternal and peripartum infection, environmental contamination, and exposure to pathogens during delivery and the immediate postnatal period. Overall, the literature indicates that improved sanitation contributes to both infant and neonatal survival, although the magnitude of the relationship tends to be larger once environmental exposure becomes more prominent during infancy and early childhood.

2.3 Drinking Water and Sanitation as Joint WASH Determinants

Water and sanitation are closely related components of the broader WASH environment, and much of the literature indicates that their combined improvement produces substantial reductions in childhood morbidity and mortality. Safe drinking water reduces pathogen exposure through ingestion, while sanitation limits environmental contamination from human waste. Their joint provision therefore interrupts complementary transmission pathways.

Global and multicountry analyses support this combined effect. Ummalla et al. (2022), using a 100-country panel, reported significant negative relationships between safe drinking water, sanitation, and child mortality. Sharma Waddington et al. (2023), through systematic review and meta-analysis, found that household WASH interventions reduced all-cause childhood mortality and substantially lowered diarrhoeal mortality. Merid et al. (2023) likewise reported that combined water and sanitation access was associated with a larger reduction in childhood diarrhoea than either component alone.

At the same time, sanitation may retain an independent protective effect after drinking-water access is taken into account. Gaffan et al. (2023) found that unimproved sanitation remained associated with elevated under-five mortality after controlling for water source and household wealth. Chakrabarti et al. (2024) similarly reported sanitation-related reductions in child mortality after adjustment for piped water access and socioeconomic characteristics. Conversely, inadequate sanitation can undermine improvements in water quality by permitting secondary contamination, as demonstrated in historical municipal water-disinfection evidence from Mexico (Bhalotra et al., 2021). Recent network meta-analysis further suggests that intervention effectiveness depends on baseline water conditions and that multi-component WASH packages do not automatically yield synergistic effects (Masset & Sharma Waddington, 2025). Household evidence from densely populated barangays in Sampaloc, Manila, similarly suggests that WASH components do not map onto health outcomes in a simple way: favorable household conditions coexisted with poorly rated public facilities, and reported diarrhoea was weakly associated with hygiene practices but not with clean-water availability or sanitation accessibility (Marcos et al., 2026). The literature therefore supports analyzing sanitation in relation to, rather than independently from, drinking-water access.

2.4 Socioeconomic Conditions and Sanitation-Related Health Outcomes

The health benefits associated with sanitation depend substantially on socioeconomic and spatial conditions. National income, household wealth, urban development, and public infrastructure influence both access to sanitation and the extent to which sanitation improvements translate into reductions in child mortality. Amegbor and Addae (2023) found that GDP per capita and sanitation indicators independently contributed to global variation in under-five mortality, while Prakash et al. (2022) showed that household and socioeconomic characteristics shape access to sanitation facilities and program benefits in India.

Urbanization produces a more complex pattern. Dense urban settlements can facilitate centralized sewerage and water systems because infrastructure can serve large populations efficiently, but rapid urban growth without adequate planning may create overcrowded informal settlements where drainage, sewage disposal, and service coverage remain poor. Cross-country evidence shows that urbanization can improve health outcomes under favorable infrastructure conditions but may also generate asymmetric effects when service provision lags population growth (Tripathi & Maiti, 2023). Evidence from flood-prone barangays of Marikina City similarly shows that contaminated floodwater poses persistent leptospirosis risks in dense urban communities and that enabling supports such as waste services are needed for prevention (Temporada et al., 2025).

Evidence from urban Bangladesh, Mozambique, and Mexico further shows that the health impact of sanitation depends on broader municipal systems, including wastewater containment, drainage, water quality, and service management (Bhalotra et al., 2021; Braun et al., 2024; Foster et al., 2021). Community-level sanitation coverage and population density are also important because individual households can remain exposed when neighboring households lack adequate facilities or when environmental contamination persists (Contreras et al., 2022). These findings indicate that socioeconomic conditions should be treated as integral to sanitation-health relationships rather than as peripheral controls.

2.5 Sanitation Quality and Development-Level Differences

The health effects of sanitation may vary according to the quality of the service provided. Basic sanitation generally refers to improved facilities that are not shared with other households, whereas safely managed sanitation additionally requires that excreta be safely disposed of in situ or transported and treated off-site (WHO & UNICEF, 2025). This distinction is important because an improved household toilet does not necessarily prevent environmental contamination if fecal sludge is subsequently discharged into soil, drains, or waterways.

Evidence suggests that higher-quality sanitation offers greater protection against enteric disease. Wolf et al. (2022) reported stronger reductions in childhood diarrhoea associated with higher-level sanitation services, while safely managed sanitation has been associated with lower risks of childhood stunting (Soe et al., 2023). Global burden work also indicates that health risks vary substantially across WASH service levels (Wolf et al., 2023). At the cross-national level, Falcon (2023) reported an inverse relationship between sanitation-service management and under-five mortality and undernutrition.

Nevertheless, direct mortality comparisons between basic and safely managed sanitation remain relatively limited. Much of the available evidence focuses on diarrhoea, enteric infection, or nutritional outcomes rather than all-cause child mortality. The benefits of sanitation may also depend on a country's development level. In low-income and high-mortality settings, initial improvements from open defecation or unimproved facilities to basic sanitation can generate substantial survival gains because baseline exposure to enteric pathogens is high. In more developed countries, where sanitation coverage is already widespread and child mortality is relatively low, further infrastructure improvements may yield smaller marginal mortality reductions.

2.6 Synthesis of the Literature

The reviewed literature consistently indicates that improved sanitation is associated with better child-survival outcomes. Across household surveys, multicountry analyses, quasi-experimental programs, and systematic reviews, access to improved sanitation is generally linked with lower under-five, infant, and neonatal mortality. The principal mechanism is the reduction of fecal-oral pathogen transmission, with additional benefits occurring through reduced diarrhoeal disease, improved nutritional status, and lower exposure to environmentally mediated infections (Chakrabarti et al., 2024; Gaffan et al., 2023; Sharma Waddington et al., 2023; Wolf et al., 2022). Evidence also suggests that community-wide sanitation coverage may generate greater protection than isolated household improvements because children remain exposed when environmental contamination persists beyond the household (Contreras et al., 2022; Kmush et al., 2021).

At the same time, sanitation operates within a broader WASH and socioeconomic system. Safe drinking water and sanitation frequently improve together and jointly reduce disease exposure. Several studies indicate that sanitation retains an independent association with child survival after water access is considered, although the magnitude of this relationship may decline once overlapping WASH conditions are controlled (Gaffan et al., 2023; Ummalla et al., 2022). Economic development, household resources, urbanization, health infrastructure, and population density further influence the extent to which sanitation improvements translate into mortality reductions (Amegbor & Addae, 2023; Foster et al., 2021; Tripathi & Maiti, 2023).

The literature also suggests heterogeneity according to the level and quality of sanitation. Safely managed or sewered services may offer stronger protection against enteric disease because they address not only household separation from excreta but also subsequent containment and treatment (WHO & UNICEF, 2025; Wolf et al., 2023).

However, the largest marginal improvements may occur in high-mortality settings where populations move from open defecation or unimproved facilities toward basic sanitation. Overall, the literature supports sanitation as an important determinant of child survival while emphasizing that its effects are conditional on water access, socioeconomic development, service quality, and the wider public-health environment.

2.7 Research Gaps

Recent studies have expanded the empirical evidence on sanitation and child mortality, including analyses based on World Development Indicators and panel methods. Lu and Mao (2025) examined rural sanitation and under-five survival in China; Annisa et al. (2026) analyzed water, sanitation, and under-five mortality across 11 Southeast Asian countries using regularized panel machine learning; Rathnasekara and Jayathilaka (2026) used a two-decade fixed-effects panel for 45 African countries; and Rajapakse et al. (2025) examined economic and healthcare determinants of under-five mortality in low-income countries. Global work also exists, including the 100-country analysis of Ummalla et al. (2022).

Despite these advances, several gaps remain. First, much of the recent panel evidence is geographically or income-group specific, while global studies have generally used narrower samples or have not jointly examined multiple stages of child mortality. Second, many studies analyze sanitation together with other WASH variables, making the independent contribution of sanitation difficult to identify. A particularly important question is whether sanitation remains associated with lower child mortality after drinking-water access is explicitly incorporated into the same fixed-effects model.

Third, existing studies often focus on under-five mortality alone. Sanitation may affect infant and neonatal mortality differently because environmental exposure and causes of death vary across stages of early life. Fourth, relatively limited longitudinal evidence compares basic and safely managed sanitation in relation to mortality. Finally, the distinction between cross-country differences and within-country change is not always made explicit, even though countries with high sanitation coverage also tend to have higher incomes, stronger health systems, and better water access.

The present study addresses these gaps through a 2000–2023 multinational panel covering 185 countries and economies. It jointly examines basic sanitation, drinking-water access, under-five, infant, and neonatal mortality; incorporates country and year fixed effects; evaluates safely managed sanitation as an alternative exposure; and tests robustness in a fully balanced 24-year country panel.

3. Methodology

3.1 Data and Variables

The study employed a quantitative longitudinal panel design using country-level data from the World Bank's World Development Indicators (WDI) database (World Bank, n.d.). The unit of analysis was the country-year observation, allowing changes in sanitation access and child mortality to be examined both across countries and within the same countries over time.

The principal study period covered 2000–2023. Although several sanitation and mortality indicators extended to 2024 in the database, the 2024 observations for some control variables—particularly current health expenditure—were substantially incomplete. Restricting the main analysis to 2000–2023 therefore provided a more consistent and analytically complete 24-year panel.

Regional aggregates, income-group classifications, and other non-country WDI groupings were excluded. The resulting complete-case core analytical panel contained 4,287 country-year observations from 185 countries and economies. A balanced-panel subsample consisting of 155 countries with complete observations across all 24 years was additionally constructed for robustness analysis.

The principal explanatory variable was basic sanitation access, measured as the percentage of the population using at least basic sanitation services (SH.STA.BASS.ZS). A second sanitation measure, safely managed sanitation services (SH.STA.SMSS.ZS), was used in supplementary models. The distinction between basic and safely managed sanitation followed the WHO/UNICEF Joint Monitoring Programme service ladder (WHO & UNICEF, 2025). Because safely managed sanitation data were available for fewer countries, it was treated as an alternative rather than the principal exposure.

The main dependent variable was the under-five mortality rate (SH.DYN.MORT), expressed as deaths before age five per 1,000 live births. Infant mortality (SP.DYN.IMRT.IN) and neonatal mortality (SH.DYN.NMRT) were examined as additional outcomes. Because sanitation and drinking-water access form interconnected components of the WASH environment, people using at least basic drinking-water services (% of population; SH.H2O.BASW.ZS) was included as a key control variable.

Three additional socioeconomic and health-system controls were included. GDP per capita, purchasing power parity, constant international prices (NY.GDP.PCAP.PP.KD) was transformed using the natural logarithm because of its skewed distribution. Current health expenditure as a percentage of GDP (SH.XPD.CHEX.GD.ZS) represented national health-resource allocation, while urban population as a percentage of total population (SP.URB.TOTL.IN.ZS) accounted for differences in settlement patterns and infrastructure concentration. Missing values were treated as unavailable observations and were not statistically imputed.

3.2 Analytical Strategy

The analysis proceeded in stages. First, descriptive statistics were generated for the principal variables, including means, standard deviations, medians, ranges, and annual averages. Longitudinal trends in sanitation access, drinking-water coverage, under-five mortality, infant mortality, and neonatal mortality were examined across the 2000–2023 period. Second, Pearson correlation coefficients were calculated to describe bivariate relationships among WASH indicators and mortality outcomes. These correlations were interpreted descriptively because they combine cross-country differences with longitudinal change.

The principal inferential analysis used two-way fixed-effects panel regression. The first specification examined sanitation without drinking-water access: $\text{Mortality}_{it} = \beta_1 \text{Sanitation}_{it} + \beta_2 \text{LnGDP}_{it} + \beta_3 \text{HealthExp}_{it} + \beta_4 \text{Urban}_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$. A second specification added basic drinking-water access: $\text{Mortality}_{it} = \beta_1 \text{Sanitation}_{it} + \beta_2 \text{Water}_{it} + \beta_3 \text{LnGDP}_{it} + \beta_4 \text{HealthExp}_{it} + \beta_5 \text{Urban}_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$.

Country fixed effects (α_i) controlled for relatively stable national characteristics that might influence both sanitation and mortality, while year fixed effects (λ_t) controlled for global changes shared across countries. Standard errors were clustered at the country level to address heteroskedasticity and serial correlation across repeated observations from the same country. This specification follows standard panel-data practice for estimating within-country associations while accounting for time-invariant heterogeneity (Wooldridge, 2010). Similar two-way fixed-effects specifications have been applied to health-system and health-outcome indicators in ASEAN country panels (Atento & Quinto, 2026; Patron et al., 2026; Quinto et al., 2026).

Under-five mortality served as the primary outcome. The fully adjusted model was subsequently estimated using infant mortality and neonatal mortality to determine whether the sanitation relationship was consistent across stages of early childhood. A supplementary model replaced basic sanitation with safely managed sanitation. Robustness analyses repeated the principal model using the balanced panel of 155 countries with complete observations across 2000–2023 and compared models with and without drinking-water access.

Regression results were evaluated using coefficient direction, magnitude, 95% confidence intervals, and probability values, with statistical significance assessed at $\alpha = .05$. Because the study used observational country-level data, coefficients were interpreted as associations rather than causal treatment effects.

3.3 Ethical Considerations

The study used only publicly available, aggregated country-level secondary data from the World Development Indicators database. No individual participants, personally identifiable information, medical records, or confidential data were included. The analysis therefore involved no participant recruitment, informed consent, clinical intervention, or direct risk to human subjects.

Responsible secondary-data practices were followed by preserving official indicator definitions, documenting exclusions and transformations, avoiding artificial imputation of unavailable observations, and interpreting findings within the limitations of an observational ecological design. Although fixed-effects models reduce several forms of confounding, they do not eliminate all possible time-varying unobserved influences. Accordingly, the study reports whether sanitation access was associated with child mortality rather than asserting that changes in sanitation alone caused observed mortality changes.

4. Results and Discussion

4.1 Descriptive Characteristics and Longitudinal Trends

The core analytical sample consisted of 4,287 country-year observations from 185 countries and economies covering the period 2000–2023. Of these, 155 countries had complete observations across all 24 years and were included in the balanced-panel robustness analysis.

Table 1. Descriptive Statistics of the Core Analytical Sample

Variable	N	Mean	SD	Median	Range
Basic sanitation access (%)	4,287	72.73	29.55	86.24	2.97–100.00
Basic drinking-water access (%)	4,287	85.72	17.68	93.54	18.76–100.00
Under-five mortality rate	4,287	36.44	40.21	20.10	1.30–489.30
Infant mortality rate	4,287	26.27	24.52	17.10	1.30–239.90
Neonatal mortality rate	4,287	14.81	11.94	11.20	0.60–59.60
Current health expenditure (% GDP)	4,287	6.23	2.86	5.68	1.22–27.09
GDP per capita, PPP	4,287	21,883.29	23,877.04	12,979.76	711.98–149,025.12
Urban population (%)	4,287	56.97	22.81	58.33	8.04–100.00

Note. Source: Authors' calculations from World Development Indicators (World Bank, n.d.).

Considerable international variation was evident in both sanitation conditions and child mortality. Basic sanitation access averaged 72.73% but ranged from less than 3% to universal coverage. Under-five mortality averaged 36.44 deaths per 1,000 live births, with similarly substantial variation across countries.

Longitudinal trends in the balanced panel showed considerable progress over the study period. Average basic sanitation coverage increased from 65.49% in 2000 to 78.62% in 2023, while basic drinking-water access rose from 80.87% to 89.68%. Mean under-five mortality fell from 56.16 to 24.91 deaths per 1,000 live births, infant mortality decreased from 38.43 to 18.75, and neonatal mortality declined from 19.67 to 11.40. The simultaneous expansion of WASH coverage and decline in child mortality demonstrates a strong descriptive relationship but also reinforces the need for multivariable panel analysis because sanitation, water access, economic development, and mortality all improved over the same period.

4.2 Bivariate Relationships

The correlation analysis showed strong negative associations between sanitation access and all three child-mortality indicators.

Table 2. *Selected Correlations Among WASH and Child-Mortality Indicators*

Variables	Basic Sanitation	Basic Water	Under-5 Mortality	Infant Mortality	Neonatal Mortality
Basic sanitation	1.000				
Basic drinking water	.881	1.000			
Under-five mortality	-.836	-.842	1.000		
Infant mortality	-.853	-.845	.978	1.000	
Neonatal mortality	-.850	-.799	.900	.938	1.000

Note. Source: Authors' calculations from World Development Indicators (World Bank, n.d.).

Basic sanitation access was strongly negatively correlated with under-five mortality ($r = -.836$), infant mortality ($r = -.853$), and neonatal mortality ($r = -.850$). Basic drinking-water access showed similarly strong negative relationships with under-five mortality ($r = -.842$) and infant mortality ($r = -.845$).

The sanitation and drinking-water indicators were themselves highly correlated ($r = .881$). This finding is important because countries with higher sanitation coverage also tend to have substantially greater access to basic drinking water. Models that examine sanitation without accounting for water access may therefore overstate the independent association attributable specifically to sanitation.

4.3 Basic Sanitation and Under-Five Mortality

The principal regression analysis first estimated the relationship between basic sanitation and under-five mortality without controlling for basic drinking-water access and then introduced drinking-water access in the fully adjusted model.

Table 3. *Two-Way Fixed-Effects Models for Under-Five Mortality*

Predictor	Model 1 β	p	Model 2 β	p
Basic sanitation (%)	-0.775	<.001	-0.288	.070
Basic drinking water (%)	—	—	-1.710	<.001
ln GDP per capita	-5.122	.230	1.124	.743
Health expenditure (% GDP)	-0.105	.832	-0.131	.747
Urban population (%)	-0.514	.063	-0.208	.304
Observations	4,287		4,287	
Countries	185		185	
R ²	.912		.928	

Note. Country and year fixed effects included. Standard errors clustered by country. Source: Authors' calculations from World Development Indicators (World Bank, n.d.).

In Model 1, basic sanitation was strongly and negatively associated with under-five mortality after controlling for economic development, health expenditure, urbanization, country fixed effects, and year fixed effects ($\beta = -0.775$, 95% CI [-1.125, -0.425], $p < .001$). A 10-percentage-point increase in basic sanitation coverage was therefore associated with approximately 7.75 fewer under-five deaths per 1,000 live births, conditional on the other variables in the model.

When basic drinking-water access was introduced in Model 2, the sanitation coefficient declined in magnitude from -0.775 to -0.288, a reduction of approximately 63%, and was no longer statistically significant at the conventional .05 level (95% CI [-0.600, 0.023], $p = .070$). By contrast, basic drinking-water access was strongly negatively associated with under-five mortality ($\beta = -1.710$, 95% CI [-2.169, -1.252], $p < .001$). Thus, although sanitation retained the expected negative direction, a substantial portion of its apparent association with under-five mortality overlapped with concurrent improvements in drinking-water access.

The socioeconomic controls were not independently significant in the fully adjusted under-five model. This should not be interpreted as indicating that income, health expenditure, or urbanization are unimportant for child

survival. Rather, country fixed effects, year fixed effects, and the highly correlated WASH variables absorb substantial portions of the variation in these indicators.

4.4 Infant and Neonatal Mortality

The same fully adjusted two-way fixed-effects model was estimated using infant and neonatal mortality as alternative outcomes.

Table 4. *Two-Way Fixed-Effects Models for Early-Life Mortality*

Predictor	Infant β	p	Neonatal β	p
Basic sanitation (%)	-0.231	.006	-0.159	<.001
Basic drinking water (%)	-0.908	<.001	-0.190	<.001
ln GDP per capita	-2.822	.135	-3.305	<.001
Health expenditure (% GDP)	-0.160	.451	-0.121	.185
Urban population (%)	-0.104	.341	-0.083	.057
Observations	4,287		4,287	
Countries	185		185	

Note. Country and year fixed effects included. Standard errors clustered by country. Source: Authors' calculations from World Development Indicators (World Bank, n.d.).

Basic sanitation retained a statistically significant negative association with infant mortality after controlling for drinking-water access and the remaining covariates ($\beta = -0.231$, 95% CI $[-0.395, -0.066]$, $p = .006$). A 10-percentage-point increase in sanitation coverage was therefore associated with approximately 2.31 fewer infant deaths per 1,000 live births.

The association was also significant for neonatal mortality ($\beta = -0.159$, 95% CI $[-0.228, -0.089]$, $p < .001$), corresponding to approximately 1.59 fewer neonatal deaths per 1,000 live births for every 10-percentage-point increase in sanitation coverage. Basic drinking-water access remained significantly associated with lower mortality in both models.

4.5 Safely Managed Sanitation and Robustness Analysis

4.5.1 Safely Managed Sanitation

A supplementary model replaced basic sanitation with safely managed sanitation. The safely managed sanitation sample contained 3,103 country-year observations from 134 countries, reflecting lower international data availability than for basic sanitation. After controlling for basic drinking-water access, GDP per capita, health expenditure, urbanization, country fixed effects, and year fixed effects, safely managed sanitation was not independently associated with under-five mortality ($\beta = -0.032$, 95% CI $[-0.217, 0.153]$, $p = .735$). Basic drinking-water access remained strongly associated with lower under-five mortality in the same model ($\beta = -1.750$, $p < .001$).

The absence of a significant safely managed sanitation coefficient should be interpreted cautiously. Safely managed sanitation is concentrated in countries with relatively high sanitation coverage and lower baseline mortality, and its measurement is available for fewer countries. These characteristics reduce both sample size and within-country variation. Importantly, when basic sanitation was estimated using the same restricted sample available for safely managed sanitation, it remained negatively associated with under-five mortality ($\beta = -0.536$, $p = .019$).

4.5.2 Balanced-Panel Robustness Test

The principal under-five mortality model was repeated using the 155 countries with complete data across all 24 years, producing 3,720 observations. In this balanced panel, basic sanitation was significantly associated with lower under-five mortality ($\beta = -0.409$, 95% CI approximately $[-0.787, -0.030]$, $p = .034$), while basic drinking-water access also remained strongly negative and significant ($\beta = -1.699$, $p < .001$).

The re-emergence of statistical significance for sanitation in the balanced panel suggests that the marginal result in the full unbalanced sample was partly sensitive to differences in country-year data availability. Across the robustness analyses, the sanitation coefficient remained negative, was significant for infant and neonatal mortality, and became significant for under-five mortality in the balanced-country panel.

4.6 Discussion

4.6.1 Sanitation and Under-Five Mortality

The results broadly support the literature linking improved sanitation with better child-survival outcomes while demonstrating that sanitation does not operate independently from drinking-water access and broader development conditions. The descriptive evidence was particularly strong: sanitation coverage increased substantially between 2000 and 2023 while under-five, infant, and neonatal mortality declined markedly. The raw correlations between sanitation and the three mortality outcomes ranged from approximately $-.84$ to $-.85$, consistent with multinational evidence showing substantially higher mortality under inadequate sanitation conditions (Amegbor & Addae, 2023; Gaffan et al., 2023).

When drinking-water access was excluded, sanitation showed a large and highly significant association with under-five mortality. This finding is broadly consistent with observational and quasi-experimental studies reporting lower child mortality following sanitation improvements (Chakrabarti et al., 2024; Mohamed, 2024). The relationship weakened substantially after drinking-water access was added, with the sanitation coefficient declining by approximately 63% while water remained strongly associated with lower mortality. This attenuation is substantively important because sanitation and drinking-water access tend to improve together and operate through overlapping disease-transmission pathways.

4.6.2 The Joint WASH Environment

The findings support treatment of water and sanitation as complementary public-health infrastructure. Previous work shows that combined WASH improvements can reduce childhood mortality and diarrhoeal disease, although intervention effectiveness depends on baseline service conditions and implementation context (Masset & Sharma Waddington, 2025; Sharma Waddington et al., 2023; Ummalla et al., 2022). The present results fit this interpretation: water access remained a strong independent correlate of under-five, infant, and neonatal mortality, while sanitation retained significant associations with infant and neonatal mortality and re-emerged as significant for under-five mortality in the balanced panel.

The appropriate interpretation is therefore not that water matters while sanitation does not. Rather, child survival is associated with the combined quality of the WASH environment, and the independent contribution attributed to one component depends partly on model specification and data structure.

4.6.3 Sanitation and Infant Mortality

The significant association between sanitation and infant mortality provides additional evidence that sanitation contributes independently to early-life survival. A 10-percentage-point increase in sanitation coverage was associated with approximately 2.31 fewer infant deaths per 1,000 live births after adjustment for drinking-water access and other covariates. This finding is consistent with prior studies showing lower infant mortality following sanitation expansion, including India's large-scale sanitation program (Chakrabarti et al., 2024).

The mechanism is plausible because infants experience increasing exposure to environmental pathogens as they progress through crawling, complementary feeding, and direct interaction with contaminated household surroundings. The magnitude of the sanitation coefficient was smaller than the corresponding drinking-water coefficient, again emphasizing that both components contribute to the household disease environment.

4.6.4 Sanitation and Neonatal Mortality

The significant neonatal finding is noteworthy because deaths in the first 28 days of life are often dominated by prematurity, delivery complications, congenital conditions, and immediate postnatal care. Nevertheless, sanitation remained negatively associated with neonatal mortality after full adjustment. Previous studies have similarly reported lower neonatal mortality among women living in households or communities with improved sanitation (Kamal & Shakeel, 2021; Kmush et al., 2021). Proposed mechanisms include reduced maternal infection, cleaner delivery environments, lower pathogen exposure, and improved household hygiene.

The relatively smaller sanitation coefficient compared with the unadjusted under-five relationship is consistent with the expectation that environmental sanitation becomes increasingly important as children's exposure broadens after the neonatal period.

4.6.5 Socioeconomic Development and Urbanization

GDP per capita, health expenditure, and urbanization were not consistently significant in the fully adjusted under-five model. This should not be interpreted as contradicting the extensive literature showing that socioeconomic development influences child survival. Recent panel analyses continue to identify economic, health-system, demographic, and infrastructure determinants of under-five mortality, although coefficient stability varies across model specifications and country groups (Rajapakse et al., 2025; Rathnasekara & Jayathilaka, 2026). Two-way fixed-effects evidence from ASEAN economies likewise found that GDP per capita growth was statistically weak for both under-five and neonatal mortality (Atento & Quinto, 2026).

In the present fixed-effects specification, much of the cross-national socioeconomic gradient may already be absorbed by country effects, year effects, and highly correlated infrastructure variables. This distinction illustrates why descriptive international comparisons and within-country panel estimates should not be treated as equivalent. A related ASEAN study of women's business leadership found that a strong pooled cross-country association disappeared once country heterogeneity was controlled, illustrating the same risk that between-country differences may be mistaken for within-country relationships (Tabujara et al., 2026).

4.6.6 Basic Versus Safely Managed Sanitation

The absence of a significant safely managed sanitation coefficient deserves particular attention. The literature suggests that safely managed or sewerage sanitation should theoretically provide greater pathogen containment because safe management addresses the full sanitation chain rather than merely separating excreta from immediate human contact (WHO & UNICEF, 2025; Wolf et al., 2023). However, the present analysis did not find an independent relationship between safely managed sanitation and under-five mortality after full adjustment.

Several explanations are possible. Safely managed sanitation data were available for fewer countries and observations; countries with high safely managed coverage tend already to have relatively low child mortality; and the largest survival gains may occur earlier in the sanitation transition, when populations move from open defecation or unimproved facilities to basic sanitation. The finding therefore does not imply that safely managed sanitation lacks public-health value. Its additional benefits may instead be expressed through outcomes such as diarrhoea, environmental contamination, dignity, convenience, and longer-term disease reduction (Soe et al., 2023; Wolf et al., 2022).

4.6.7 Implications of the Balanced-Panel Results

The balanced-panel analysis strengthens the evidence for an independent sanitation relationship. Among the 155 countries with complete observations across the entire 24-year period, sanitation remained significantly associated with lower under-five mortality even after drinking-water access and other controls were included. This suggests that the marginal nonsignificance observed in the larger unbalanced panel may partly reflect differences in the countries and years contributing observations to the model.

The result also illustrates the value of sensitivity analysis in multinational panel research. A coefficient should not be judged solely according to whether one particular model crosses the conventional $p = .05$ threshold. Direction, magnitude, confidence intervals, consistency across related outcomes, and robustness to alternative samples provide a more complete assessment. A comparable pattern appears in ASEAN panel evidence in which immunization coverage, used as a proxy for primary healthcare capacity, was not significant in level fixed-effects models but was significantly associated with tuberculosis incidence in a lagged log specification (Quinto et al., 2026).

4.6.8 Overall Interpretation

Taken together, the findings support four principal conclusions. First, countries with greater sanitation access generally experience substantially lower child mortality, and improvements in sanitation have accompanied major global gains in child survival since 2000. Second, sanitation cannot be interpreted independently from drinking-water access because the two indicators are highly correlated and controlling for water substantially reduces the estimated sanitation association with under-five mortality. Third, sanitation nevertheless retains evidence of an independent relationship with child survival because it remained significantly associated with infant and neonatal mortality and with under-five mortality in the balanced-panel analysis. Fourth, the largest mortality benefits may arise during the transition from poor or unimproved sanitation toward broad basic sanitation coverage, whereas safely managed sanitation did not show an additional independent mortality association in the present global panel.

The principal contribution of the study is consequently not simply to reaffirm that sanitation and child mortality are negatively correlated. Rather, it demonstrates that the magnitude and statistical independence of the sanitation relationship change considerably once drinking-water access, fixed country characteristics, common global trends, mortality stage, sanitation service level, and panel composition are taken into account. This extends recent regional and global panel evidence by combining a larger multinational sample with multiple mortality outcomes and alternative sanitation specifications (Annisa et al., 2026; Lu & Mao, 2025; Rathnasekara & Jayathilaka, 2026; Ummalla et al., 2022).

5. Conclusions and Recommendations

5.1 Conclusions

This study examined the relationship between sanitation access and child mortality across countries from 2000 to 2023 using a longitudinal panel drawn from the World Development Indicators database. Basic sanitation access was analyzed as the principal explanatory variable, while under-five mortality served as the primary outcome. Infant mortality and neonatal mortality were examined as additional early-life outcomes, and drinking-water access, economic development, health expenditure, and urbanization were incorporated as controls.

The findings confirm that sanitation and child survival are strongly related at the descriptive level. Countries with higher basic sanitation coverage generally exhibited substantially lower under-five, infant, and neonatal mortality. However, the multivariable panel analysis demonstrated that the sanitation-child mortality relationship is not independent from the broader WASH environment.

Basic sanitation was strongly associated with lower under-five mortality when drinking-water access was not included in the model. After water access was incorporated, the sanitation coefficient declined by approximately 63% and became marginally nonsignificant in the full unbalanced-panel model. Nevertheless, sanitation remained significantly associated with infant and neonatal mortality, and it was again significantly associated with under-five mortality in the balanced panel of 155 countries.

Safely managed sanitation did not exhibit an additional independent association with under-five mortality in the fully adjusted model. This may reflect lower sample coverage, reduced within-country variation, and the possibility that the largest child-survival gains occur earlier in the sanitation transition, particularly when populations move from open defecation or unimproved facilities toward basic sanitation.

Overall, the study concludes that basic sanitation is an important component of child survival, but its effects are embedded within a wider WASH and development system. Sanitation improvements are associated with lower child mortality, yet their estimated contribution changes substantially when drinking-water access and longitudinal country characteristics are taken into account.

5.2 Recommendations

Governments should avoid treating sanitation as an isolated infrastructure objective. Sanitation investments should be coordinated with drinking-water programs, hygiene promotion, waste management, drainage, and primary healthcare because WASH components operate jointly.

Countries with low sanitation coverage should prioritize expansion of basic sanitation access, where the marginal health gains are likely to be greatest. Programs should target community-level coverage rather than only household construction because individual households may remain exposed when environmental contamination persists around them.

Child-health policy should integrate sanitation planning with maternal and child health programs. The significant associations with infant and neonatal mortality suggest that sanitation may contribute to survival even during early life, particularly when combined with clean delivery environments, safe water, and infection prevention. Such integration may draw on community-based primary healthcare delivery; recent survey evidence from CALABARZON local government units reported high community awareness of, trust in, and support for formally integrating community health workers into primary healthcare (Morcilla & Quinto, 2026).

Governments should improve monitoring of sanitation quality. Basic coverage indicators do not fully capture whether waste is safely transported, treated, or disposed of; stronger data systems are needed for safely managed sanitation, fecal-sludge management, wastewater treatment, and environmental contamination.

Development institutions should prioritize WASH investments in high-mortality and low-coverage settings and evaluate programs using multiple health outcomes, including infant mortality, neonatal mortality, diarrhoeal disease, nutrition, and stunting rather than relying solely on under-five mortality.

5.3 Contributions of the Study

The study contributes to the sanitation and child-health literature by providing a 24-year multinational panel covering 185 countries and economies; explicitly separating sanitation from drinking-water access; comparing under-five, infant, and neonatal mortality; incorporating country and year fixed effects; evaluating both basic and safely managed sanitation; and testing robustness in a fully balanced 155-country panel.

This design extends recent panel studies that have focused on individual countries, regions, or narrower country groups (Annisa et al., 2026; Lu & Mao, 2025; Rajapakse et al., 2025; Rathnasekara & Jayathilaka, 2026) while complementing earlier global evidence based on smaller country samples (Ummalla et al., 2022).

5.4 Limitations of the Study

Several limitations should be considered. First, the study relied on country-level observational data, so the findings indicate associations rather than causal treatment effects. Time-varying unobserved factors may still influence both sanitation access and child mortality. Second, national averages may conceal substantial within-country inequalities, particularly in rural communities and informal settlements.

Third, the principal sanitation measure captures access to at least basic sanitation but does not directly measure actual facility use, maintenance, fecal-sludge treatment, sewer functionality, or environmental contamination. Fourth, sanitation and drinking-water access were highly correlated, so their independent coefficients may be sensitive to multicollinearity and shared development pathways. Fifth, safely managed sanitation data were available for fewer countries and observations, reducing statistical power and within-country variation.

Sixth, health expenditure as a percentage of GDP does not capture how effectively health resources are allocated or whether spending is directed toward maternal and child health. Seventh, ecological relationships observed at the country level should not be interpreted as individual-level effects. Finally, the models did not directly include several potentially important determinants such as maternal education, vaccination coverage, nutrition, fertility, healthcare quality, conflict, or environmental pollution.

5.5 Directions for Future Research

Future studies should examine whether the sanitation-child mortality relationship differs systematically across income groups, regions, or levels of baseline mortality and should test interactions between sanitation and drinking-water coverage. Additional determinants such as maternal education, immunization, malnutrition, fertility, skilled birth attendance, and poverty can also be incorporated where data coverage permits.

More detailed analyses of safely managed sanitation are warranted as international data coverage improves. Country-level analyses could also be complemented by subnational panel studies using districts, municipalities, or provinces, while quasi-experimental approaches could examine major sanitation programs and infrastructure rollouts to strengthen causal inference.

Finally, future work should investigate whether sanitation affects mortality indirectly through diarrhoea, stunting, wasting, and other intermediate outcomes. The findings of the present study suggest that the most informative question is not simply whether sanitation reduces child mortality, but how sanitation, water access, socioeconomic development, and health-system capacity interact to improve child survival.

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