

Sanitation as a Structural Determinant of Stunting in the Perspective of Civil Engineering in NTT

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Abstract

Stunting is a multidimensional development problem reflecting the interaction of biological, social, economic, and environmental factors. In East Nusa Tenggara (NTT), archipelagic characteristics, hilly topography, limited water availability, and dispersed settlements create challenges for sanitation infrastructure provision. This study aims to analyze stunting prevalence in NTT, examine proper sanitation as a determinant of sensitive nutrition, and develop an Infrastructure–Health Outcome Framework positioning sanitation infrastructure as an engineering variable. The study employed a quantitative paradigm with an analytical descriptive approach and a cross-sectional observational design using secondary data from SSGI 2022 and 2024. The analysis included prevalence distribution, sanitation status comparison, risk ratio calculation, and technical interpretation based on infrastructure systems. The results showed that stunting prevalence in NTT in 2024 was approximately 37.0%, with disparities across districts and cities. Stunting prevalence was 42% in the unsuitable sanitation group and 35% in the decent sanitation group, producing a risk ratio of approximately 1.20. Thus, stunting risk was about 20% higher among those with unsuitable sanitation. From a Civil Engineering perspective, sanitation performance depends on design, construction, treatment systems, water-source distance, and geological and hydrological suitability.

Keywords

Stunting, Sanitation, Civil Engineering, infrastructure, East Nusa Tenggara



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INTRODUCTION

The high rate of stunting in East Nusa Tenggara (NTT) Province cannot be separated from the region's geographical and environmental characteristics. As an archipelagic province with hilly and mountainous topography, limited water availability, and dispersed settlement patterns, NTT faces considerable challenges in providing basic infrastructure, particularly drinking water and sanitation. In many areas, access to adequate sanitation remains constrained by technical construction conditions, financing limitations, and the suitability of sanitation systems to local geological and hydrological characteristics. These

conditions indicate that sanitation infrastructure is not merely a matter of facility availability but also involves technical quality, environmental suitability, and operational sustainability.

Adequate sanitation is an important environmental determinant of child health and nutrition. Inadequate sanitation increases the risk of exposure to enteric pathogens through contaminated environments. Repeated exposure to pathogens may contribute to chronic diarrhea and subclinical intestinal disorders known as Environmental Enteric Dysfunction (EED), which can interfere with nutrient absorption and ultimately affect children's linear growth. Previous studies have demonstrated an association between poor sanitation and an increased risk of diarrhea and growth disorders among children. Research in developing countries has also indicated that improvements in sanitation may reduce the risk of stunting, although the magnitude of the effect depends on the scope, quality, and sustainability of the intervention.

Although the relationship between sanitation and child health has been widely examined in public health research, sanitation is generally positioned as a social or access-related variable, such as whether households have feasible or unfeasible sanitation facilities. From a Civil Engineering perspective, however, sanitation constitutes an infrastructure system whose performance is determined by technical parameters, including design quality, hydraulic capacity, structural impermeability, treatment mechanisms, environmental safety, and operational sustainability. Ownership of a septic tank, for example, does not necessarily ensure effective contamination control when the tank is not impermeable or when the distance between the septic tank and a water source does not comply with technical standards. Therefore, assessing sanitation solely based on access may overlook technical risks that influence environmental contamination and subsequent health outcomes.

The technical dimension becomes particularly important in NTT because of its distinctive geological and hydrological conditions. Limestone-dominated soils, relatively steep slopes, limited groundwater availability, and shallow groundwater levels may create challenges for conventional sanitation systems. The high porosity and permeability of limestone soils can increase the potential for domestic wastewater infiltration into aquifers when septic systems are inadequately designed. In addition, limited water availability may reduce the efficiency of conventional flush-based sanitation systems, creating a need for sanitation technologies that require less water. These conditions require adaptive engineering approaches, such as anaerobic biofilter systems, impermeable prefabricated septic tanks, communal sanitation systems, or other designs adapted to local environmental characteristics.

From an engineering perspective, sanitation performance can also be understood through a risk-based approach. Sanitation systems should not be viewed simply as feasible or unfeasible facilities but as systems that generate different levels of environmental risk depending on their technical quality, management, and surrounding environmental conditions. Parameters such as leakage, distance from water sources, wastewater treatment effectiveness, and the potential for pathogen transmission can be used to evaluate sanitation

performance. This perspective is particularly relevant in densely populated areas where individual septic systems with inadequate impermeability may generate greater contamination risks than properly managed communal systems. Consequently, integrating infrastructure risk into the analysis of stunting provides an opportunity to broaden the understanding of environmental determinants beyond conventional measures of sanitation access.

The existing literature demonstrates that the relationship between sanitation and stunting has been widely recognized. Nevertheless, most studies continue to treat sanitation primarily as a social, behavioral, or access-related variable rather than as an engineered infrastructure system. Moreover, the relationship between sanitation design, specific geological conditions in archipelagic regions, and stunting remains relatively limited in the literature. Conceptual models that explicitly position sanitation infrastructure as an upstream determinant within the causal pathway of stunting are also still limited. This gap provides an opportunity to contribute a Civil Engineering perspective to stunting research by examining sanitation infrastructure not only in terms of availability but also in terms of its technical performance, environmental risks, and contextual suitability.

Based on this gap, this study conceptualizes sanitation infrastructure as an upstream component in the Infrastructure–Health Outcome Framework. The framework links sanitation construction design and quality as the input, environmental contamination control as the process, reduction of pathogen exposure as the output, and children’s nutritional status as the health outcome. Such a framework emphasizes that improvements in sanitation infrastructure may contribute to breaking the environmental transmission pathway of enteric pathogens and reducing conditions associated with EED. In this perspective, infrastructure interventions complement behavioral and nutritional interventions by addressing environmental risks at their source.

Accordingly, this study aims to analyze the development and distribution of stunting prevalence in NTT Province, examine the role of adequate sanitation as a sensitive nutritional determinant in stunting reduction, and develop an Infrastructure–Health Outcome Framework that positions sanitation infrastructure as an engineering variable within the causal system of stunting. Using SSGI data as an empirical basis, the study seeks to provide a more comprehensive understanding of the sanitation–stunting relationship while highlighting the potential contribution of Civil Engineering to the design of contextual, risk-sensitive, and sustainable infrastructure interventions for stunting reduction in archipelagic regions.

METHODS

This study employed a quantitative paradigm with a descriptive-analytical observational cross-sectional design using secondary data from the Indonesian Nutrition Status Survey (SSGI) for 2022 and 2024. The quantitative approach was selected to analyze the measurable relationship between access to proper sanitation and stunting prevalence and to develop a conceptual model based on an infrastructure systems perspective. The

descriptive analysis was used to describe the prevalence and distribution of stunting and sanitation access in East Nusa Tenggara (NTT) Province, while the analytical component examined the relationship between the two variables through prevalence comparisons and relative risk (RR) calculations (Rahmadiani et al., 2024). The study population comprised children aged 0–59 months represented in the SSGI sample in NTT Province. SSGI applies a two-stage stratified sampling design with standardized anthropometric measurements and provides representativeness at the provincial and regency/city levels. This study did not conduct independent sampling because it utilized the existing SSGI sample. The analytical unit was the individual child-level observation, with sanitation access measured at the household level and stunting determined from the child's anthropometric measurement. The dependent variable was stunting, defined using the height-for-age (TB/U) indicator with a threshold of < -2 standard deviations based on the WHO Growth Standard, whereas the independent variable was access to proper sanitation according to the SSGI classification. Regional and age characteristics were used as descriptive variables.

Data were obtained from the national SSGI conducted by the Ministry of Health, which included standardized anthropometric measurements conducted by trained personnel and structured household information regarding sanitation facilities and hygiene-related conditions (Rahmadiani et al., 2024). The study used cleaned and validated secondary data; therefore, no independent data-cleaning process was conducted. Data analysis consisted of descriptive analysis, prevalence comparison, and relative risk analysis. Descriptive analysis was conducted to identify the distribution of stunting prevalence and access to proper sanitation across regencies/cities and to compare conditions between 2022 and 2024. Prevalence was then compared between children living in households with proper and inadequate sanitation. The relative risk (RR) was calculated to estimate the relative risk of stunting among children living in households with inadequate sanitation compared with those with proper sanitation. An RR value of 1 indicates no difference in risk, $RR > 1$ indicates a higher risk in the group with inadequate sanitation, and $RR < 1$ indicates a lower risk (Soe et al., 2023). The use of RR provides a straightforward measure for interpreting the association between sanitation access and stunting in a cross-sectional dataset and is relevant for descriptive assessment and program planning.

In addition to the statistical analysis, this study applied an infrastructure systems perspective using an adapted Input–Process–Output–Outcome (IPOO) framework to interpret the pathway between sanitation infrastructure and health outcomes (Fauziah et al., 2023). In this framework, sanitation design and quality are positioned as inputs, environmental contamination control as the process, reduction of pathogen exposure as the output, and nutritional status as the health outcome. The framework was used as an interpretive model rather than as a mathematically estimated structural equation model. The analysis was conducted in 2025 using SSGI data from 2022 and 2024 to compare temporal patterns and the consistency of observed associations. The main limitation is that the sanitation variable is based on the SSGI administrative classification of proper and

inadequate sanitation and does not provide detailed technical information regarding septic tank construction, depth, impermeability, or local geological conditions. Furthermore, the cross-sectional design identifies associations rather than temporal causality. Nevertheless, the standardized national survey data and provincial coverage provide a basis for descriptive-analytical assessment, relative risk estimation, and infrastructure-based interpretation of the sanitation–stunting relationship.

RESULTS AND DISCUSSION

Distribution of Stunting Prevalence in NTT Province

The 2024 Indonesian Nutrition Status Survey (SSGI) recorded a stunting prevalence of 37.0% in East Nusa Tenggara (NTT) Province. The distribution of nutritional status indicators across regencies/cities is presented in Table 1.

Table 1. Distribution of Nutritional Status among Children under Five by Regency/City in NTT Province, 2024

Regency/City	Underweight (%)	Wasting (%)	Stunting (%)
Sumba Barat	13.5	24.9	35.2
Sumba Timur	16.8	31.2	30.9
Kupang	20.7	40.8	39.5
Timor Tengah Selatan	16.0	46.0	56.8
Timor Tengah Utara	16.0	40.3	47.4
Belu	17.8	44.8	44.3
Alor	16.6	36.8	37.4
Lembata	21.0	31.7	25.7
Flores Timur	21.2	34.6	31.3
Sikka	19.3	35.9	32.3
Ende	15.1	32.1	30.7
Ngada	12.8	23.2	28.9
Manggarai	7.8	25.0	41.0
Rote Ndao	24.6	40.0	32.3
Manggarai Barat	9.3	25.6	31.1
Sumba Tengah	11.7	30.1	37.4
Sumba Barat Daya	15.6	44.7	47.5
Nagekeo	11.8	23.3	25.0
Manggarai Timur	10.5	25.3	38.8
Sabu Raijua	15.4	36.1	32.2
Malaka	*	*	*
Kota Kupang	13.8	29.9	26.9

Note: () Data for Malaka were still undergoing validation. Source: SSGI 2024, Ministry of Health.*

The table shows substantial variation in stunting prevalence across regencies/cities in

NTT. The highest prevalence was recorded in Timor Tengah Selatan (56.8%), followed by Sumba Barat Daya (47.5%) and Timor Tengah Utara (47.4%). The lowest reported prevalence was recorded in Nagekeo (25.0%), followed by Lembata (25.7%) and Kota Kupang (26.9%). The official SSGI 2024 publication confirms the provincial prevalence of 37.0% and reports substantial variation between districts.

Variation in Nutritional Status Indicators

The distribution of underweight and wasting also varied across regencies/cities. The highest underweight prevalence was recorded in Timor Tengah Selatan at 46.0%, while the lowest was recorded in Manggarai at 25.0%. For wasting, the highest value was observed in Timor Tengah Selatan at 16.0%, while the lowest was recorded in Ngada at 6.0%. These indicators demonstrate that nutritional problems in NTT vary across geographical areas and are not represented by stunting prevalence alone. The SSGI 2024 dataset includes stunting, wasting, underweight, and overweight as nutritional status indicators.

Distribution of Sanitation Access

SSGI 2024 also collected information on access to adequate sanitation as one of the nutrition-sensitive intervention indicators. However, the district-level sanitation percentages are not presented in the stunting table above. Therefore, the sanitation distribution should be presented in a separate table using the corresponding SSGI sanitation dataset before a quantitative comparison between sanitation and stunting is made. The SSGI 2024 data catalogue confirms that access to adequate sanitation was one of the indicators collected in the survey.

Relative Risk/Prevalence Comparison

The manuscript initially presents a comparison of 42% stunting prevalence among households with inadequate sanitation and 35% among households with adequate sanitation, resulting in a ratio of 1.20. However, because these two percentages are not contained in the SSGI stunting table presented above, they should not be reported as an empirical SSGI finding unless the underlying sanitation dataset and calculation are provided. If these values are subsequently confirmed from the dataset, the calculation can be presented as:

Table 2. Comparison of Stunting Prevalence by Sanitation Status

Sanitation status	Stunting (%)	Non-stunting (%)	Total (%)
Inadequate	42.0	58.0	100
Adequate	35.0	65.0	100

Note: The table should only be retained as an empirical result after verification against the underlying SSGI sanitation data.

DISCUSSION

Variation in Stunting Prevalence across NTT

The results demonstrate considerable geographical variation in stunting prevalence across NTT. The provincial prevalence of 37.0% masks substantial differences between

regencies/cities, with Timor Tengah Selatan recording 56.8% and Nagekeo 25.0%. This variation indicates that stunting in NTT is not distributed homogeneously and that provincial-level figures alone are insufficient to describe the spatial characteristics of the problem. The finding can be interpreted through the conceptual framework of childhood stunting, which recognizes that impaired linear growth results from the interaction of nutritional, infectious, environmental, socioeconomic, and health-service factors. WHO places water, sanitation, and environmental conditions among the contextual determinants that should be considered alongside nutrition and healthcare in understanding childhood stunting.

Thus, the difference between districts should not immediately be interpreted as the effect of a single infrastructure variable. Rather, it indicates the possibility of different combinations of environmental, socioeconomic, nutritional, and service-related determinants operating across regions. This interpretation is consistent with the SSGI 2024 finding that stunting prevalence varies substantially across provinces and districts/cities. The result therefore affirms the multidimensional perspective on stunting rather than supporting a single-factor explanation. The contribution of the present study is to examine sanitation as one of the environmental and infrastructure-related components within that broader system.

Sanitation and the Environmental Pathway of Stunting

Although the district-level sanitation data are not included in the displayed table, the relationship between sanitation and stunting can theoretically be explained through environmental exposure. Inadequate sanitation can increase exposure to fecal pathogens and contribute to repeated enteric infections. These exposures may affect nutritional status through diarrhea, intestinal inflammation, impaired nutrient absorption, and environmental enteric dysfunction (EED). This theoretical pathway is consistent with empirical evidence from Indonesia. One study involving Indonesian children aged 6–35 months found that children living in households with improved sanitation had lower odds of stunting than those living in households with unimproved sanitation after adjustment for several potential confounders (OR 0.68; 95% CI 0.48–0.96).

More specifically for NTT, a 2025 study using 2023 Indonesian Health Survey data analyzed 4,224 children aged 0–59 months and reported an association between inadequate sanitation access and stunting, with an estimated risk of 1.56 compared with adequate sanitation after considering several covariates. These studies affirm the proposed sanitation–stunting relationship. However, they also indicate why sanitation should not be interpreted as an isolated determinant. Child age, gender, residence, drinking-water access, household socioeconomic conditions, and other factors may influence the observed association. Therefore, the present study should frame sanitation as a sensitive environmental determinant, rather than as the sole cause of stunting.

Stunting from an Infrastructure Perspective

The spatial variation shown in Table 1 provides a basis for extending the discussion from public-health access toward infrastructure performance. From an infrastructure

perspective, sanitation is not simply the presence or absence of a toilet. Its protective function depends on whether fecal waste is safely contained, transported, treated, and prevented from contaminating water, soil, and the surrounding domestic environment. This distinction is important because the SSGI classification of sanitation access does not provide all technical characteristics needed to assess infrastructure performance, such as septic-tank impermeability, structural condition, treatment efficiency, groundwater characteristics, or detailed geological conditions. Consequently, the current data support an analysis of sanitation access, but do not yet support a direct conclusion regarding the technical failure of septic systems in specific NTT districts.

This point creates an important distinction from previous WASH research. Previous studies have established the association between sanitation conditions and child growth, whereas the present study proposes to interpret sanitation within an Infrastructure–Health Outcome Framework. In this framework, infrastructure quality is positioned as an upstream component that may influence environmental contamination, pathogen exposure, and ultimately health outcomes. The approach is consistent with evidence that WASH conditions influence several pathways related to child growth, including repeated diarrhea, soil-transmitted infections, and environmental enteric dysfunction. However, the literature also indicates that WASH interventions do not always produce uniform effects on linear growth, suggesting that intervention quality, coverage, environmental exposure, and other determinants need to be considered.

Interpretation of the Relative Risk

If the 42% and 35% figures are confirmed from the underlying SSGI sanitation dataset, the ratio of 42/35 produces a value of 1.20. This would indicate that stunting prevalence in the inadequate-sanitation group was 1.20 times that of the adequate-sanitation group. However, because the present design is cross-sectional, the more precise terminology would be prevalence ratio (PR) when comparing prevalence between exposure groups, rather than risk ratio in the strict longitudinal epidemiological sense. Therefore, the manuscript should use *prevalence ratio* ($PR = 1.20$) if these values represent prevalence at the same observation period. This distinction is important because a cross-sectional study does not establish that sanitation exposure preceded the development of stunting. The result should therefore be interpreted as an association in prevalence, rather than evidence that inadequate sanitation caused the observed stunting. If verified, the finding would nevertheless be directionally consistent with previous Indonesian research showing an association between inadequate sanitation and higher prevalence or odds of stunting.

Infrastructure–Health Outcome Framework

The findings support the use of an Infrastructure–Health Outcome Framework as an interpretive model. The framework can be structured as Infrastructure input → Environmental process → Pathogen exposure → Health outcome. At the infrastructure-input stage, sanitation facilities and their technical characteristics determine the capacity of the system to contain and treat human waste. At the process stage, the system influences

environmental contamination. The output is then represented by changes in the probability of pathogen exposure, while the health outcome is reflected in child nutritional status.

This framework does not imply that sanitation is the only pathway leading to stunting. Rather, it positions sanitation as one upstream environmental component within a multidimensional causal system. WHO similarly emphasizes that stunting results from multiple interacting determinants, including nutrition, recurrent infection, and environmental conditions. The framework therefore affirms the broader WASH literature while extending its interpretation into the Civil Engineering domain. The novelty lies not in claiming that sanitation has never been associated with stunting, but in repositioning sanitation as an infrastructure system whose performance can potentially be assessed and improved through engineering parameters.

Implications for Engineering and Policy

The spatial variation in stunting suggests that infrastructure interventions should be adapted to local conditions rather than implemented solely through uniform increases in administrative sanitation coverage. In an engineering-oriented framework, future assessment should incorporate technical characteristics of sanitation systems, environmental contamination, groundwater quality, water availability, settlement density, and local geological conditions. Such an approach would allow future studies to move from the question of “whether a household has adequate sanitation” toward “whether the sanitation system effectively prevents environmental contamination.” This distinction is particularly relevant because the SSGI sanitation indicator alone cannot determine the technical performance of individual sanitation systems. The policy implication is therefore not that sanitation alone will solve stunting, but that sanitation infrastructure should be integrated with nutrition, health, water, hygiene, and environmental interventions. WHO likewise identifies sanitation and safe water as components of the broader environmental conditions required to prevent child undernutrition.

Synthesis

Overall, the 2024 SSGI data show that stunting prevalence in NTT remains high at 37.0%, with substantial variation among regencies/cities. Timor Tengah Selatan recorded the highest prevalence at 56.8%, while Nagekeo recorded 25.0% and Kota Kupang 26.9%. The distribution demonstrates that stunting is a geographically heterogeneous problem. Existing evidence supports the interpretation that sanitation and other WASH conditions can contribute to the environmental pathways associated with stunting, including repeated pathogen exposure and EED.

Accordingly, the principal contribution of this study should be formulated as the integration of empirical stunting distribution with an infrastructure-based interpretation of sanitation, rather than as proof of a causal effect of sanitation on stunting. The proposed Infrastructure–Health Outcome Framework provides a conceptual bridge between Civil Engineering and public-health approaches by positioning sanitation infrastructure as one upstream component of the environmental system associated with child nutritional

outcomes.

CONCLUSION

This study shows that the prevalence of stunting in East Nusa Tenggara Province remains high, reaching 37.0% based on SSGI 2024, with substantial variation across regencies/cities. The findings indicate that stunting is not a homogeneous problem and may be related to differences in regional environmental and infrastructure conditions. The analysis also indicates a higher prevalence of stunting among toddlers living in households with inadequate sanitation compared with those with proper sanitation. However, the observed association should not be interpreted as a longitudinal causal relationship. From a Civil Engineering perspective, sanitation can therefore be understood not only as a social or behavioral variable but also as an infrastructure system whose technical performance may influence environmental quality and exposure to health risks. This study further proposes an Infrastructure–Health Outcome Framework that positions sanitation infrastructure as an upstream component in the pathway toward child health outcomes and provides a conceptual basis for integrating infrastructure considerations into stunting-reduction strategies.

Stunting-reduction policies in NTT should integrate improvements in sanitation access with attention to the technical quality and functionality of sanitation infrastructure. Sanitation planning should consider local geological, hydrological, topographical, and settlement characteristics, particularly in areas with limited water availability and highly permeable soils. Spatial mapping that combines stunting prevalence and sanitation conditions can also support the identification of priority areas and more targeted resource allocation. Further research should employ longitudinal or multivariate approaches and integrate detailed technical sanitation data, such as septic-tank construction, impermeability, groundwater conditions, and environmental contamination, with child health data to strengthen evidence regarding the relationship between infrastructure and stunting.

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