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The impact of food affordability and essential services on child stunting in Kalimantan

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ABSTRACT
Background: Child stunting remains a major public health issue in Indonesia, particularly in Kalimantan, where high food prices, poverty, and limited access to water, sanitation, and hygiene (WASH) intersect. This study investigates how the affordability of nutrient-rich foods, income inequality, and environmental health affect child growth outcomes. **Methods:** A quantitative cross-sectional analysis was conducted using 2024 provincial data from 5 provinces of Kalimantan. Key variables included stunting prevalence, food prices, affordability indices, poverty rate, Gini ratio, and WASH access. Nutritional affordability was assessed using the cost of nutrient adequacy (CoNA) framework, calculated as the cost per 1,000 kilocalories and per 10 grams of protein. Statistical analyses were applied using STATA 18 included Spearman's correlation and robust ordinary least squares (OLS) regression with HC3 standard errors and 1,000 bootstrap resamples. **Findings:** Results showed that affordability and improved WASH access are associated with reduced stunting, while higher poverty and inequality are linked to increased stunting. The interaction between affordability and inequality diminished the protective effect of affordability ($\beta = +2.83$, $p = 0.03$), accounting for 78% of the variance. These results demonstrate that both economic and infrastructural equity are critical determinants of child nutrition outcomes. **Conclusion:** This study presents a provincial application of the CoNA framework in Indonesia, integrating affordability, inequality, and WASH indicators within a unified econometric model to elucidate regional disparities in stunting. **Novelty/Originality of this article:** This study applying the Cost of Nutrient Adequacy (CoNA) framework at the provincial level in Indonesia and integrating food affordability, economic inequality, and WASH access within a unified econometric model to identify multidimensional determinants of stunting and inform evidence-based, equity-oriented public health strategies for vulnerable populations.

KEYWORDS: food affordability; nutrients cost; poverty; stunting; WASH.

1. Introduction

The 2030 Agenda for Sustainable Development, sets 17 Sustainable Development Goals (SDGs) to be achieved by 2030, focusing on inclusive prosperity, environmental sustainability, and human well-being. SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-Being) aim to eliminate all forms of malnutrition, while SDG 6 (Clean Water and Sanitation), SDG 10 (Reduced Inequalities), and SDG 13 (Climate Action) highlight the importance of addressing environmental and socio-economic disparities vulnerabilities (United Nation, 2015, 2025). Despite progress, undernutrition and stunting remain significant issues, especially in lower-income, climate-vulnerable regions (Sandler & Sun,

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2024). Structural barriers, such as food affordability and inadequate WASH access, continue to impede progress. Addressing these disparities will require integrated, climate-sensitive, and equity-driven nutrition strategies to improve access to nutritious food, safe water, and resilient livelihoods (Shekar et al., 2024).

According to the WHO (2025) report, approximately 150.2 million children under five years of age are affected by stunting worldwide. Stunted children experience restricted growth and may not achieve their full cognitive potential. In Indonesia, stunting remains a key public health challenge despite notable progress. Although national stunting prevalence declined from 21.5% in 2023 to 19.8% in 2024, this improvement is not consistent everywhere (Ministry of Health of the Republic of Indonesia, 2024). The government aims to lower the rate to < 5% by 2045, as outlined in Indonesia Vision 2045 (Ministry of National Development Planning of the Republic of Indonesia, 2019). In the Kalimantan region, most indicators exceed national averages, yet substantial variation exists among provinces: 26.8% in South Kalimantan, 22.9% in East Kalimantan, 22.7% in West Kalimantan, and 22.1% in Central Kalimantan. These figures highlight persistent regional disparities (Ministry of Health of the Republic of Indonesia, 2024). The National Medium-Term Development Plan notes that both economic and environmental actions are needed to address these differences (Ministry of National Development Planning of the Republic of Indonesia, 2020).

"The Social Determinants of Health" framework asserts that child growth outcomes are shaped by a wide range of social and environmental factors, rather than solely biology (World Health Organization, 2010). "Household Production Theory" further demonstrates that household purchasing power and food prices affect diet quality (Becker, 1965). Stunting persists due to factors beyond dietary insufficiency. When healthy foods cost too much, families often choose cheaper, calorie-heavy options, which keeps malnutrition going. These frameworks collectively establish how inequality and market dynamics affect nutrition (Akerele et al., 2024; Headey et al., 2024). Bai et al. (2021) put these ideas into practice with the cost of nutrient adequacy (CoNA) model, which estimates the lowest cost needed to meet energy and nutrient needs. The WASH framework looks at how environmental factors affect nutrient absorption and disease risk (Bekele et al., 2020). When these frameworks are combined, they show a double challenge: even if food is available, poor sanitation and unsafe water can reduce the benefits of a good diet. This study uses these connections to explore how affordability and WASH together affect nutrition in Kalimantan.

Despite the value of integrated frameworks, previous research has typically examined these factors in isolation. Hudaya et al. (2025) mapped the spatial distribution of stunting across Indonesian provinces, demonstrating that regional disparities are strongly linked to economic and infrastructural inequalities. Kalimantan exemplifies the convergence of economic growth and nutritional disparities, as its economy is predominantly based on natural resource extraction, which generates both wealth and inequality. High logistics costs contribute to substantially elevated food prices relative to other islands, while recurrent forest and peat fires continue to degrade farmland and water quality (Abadi et al., 2025; Anyanwu et al., 2022). Beal et al. (2018) noted that in Indonesia, environmental degradation and social inequities frequently reinforce one another, perpetuating barriers to reducing child undernutrition.

To address these persistent challenges, Ministry of Finance of the Republic of Indonesia (2023) allocates over IDR 48 trillion annually through intergovernmental transfers and village funds to support regional development. However, evidence indicates that fiscal resources alone are insufficient. For instance, fiscal measures have sought to bridge these disparities. reported that economic growth in South Kalimantan did not reduce stunting when inequality persisted. Similarly, García-Salirrosas et al. (2025) found that unequal income distribution diminishes the nutritional benefits of improved affordability. These findings highlight the need to combine fiscal interventions with equity-oriented reforms. Further complicating the issue, while calorie sufficiency has improved, micronutrient deficiencies remain common (Fernández-Gaxiola et al., 2024). Processed foods increasingly dominate household consumption, replacing traditional nutrient-dense options. As Noor et al. (2022) reported, many low-income families substitute animal protein with instant noodles during price spikes. also found that nutritious foods are disproportionately expensive in Kalimantan and cautioned that affordability alone does not guarantee dietary quality. Together, these patterns illustrate the "affordability paradox" in modern food systems (Webb et al., 2023)

In response to these interconnected challenges, this study integrates economic, social, and environmental factors into a single analysis. It uses provincial data to examine how the cost of healthy foods, income inequality, poverty, and WASH access affect stunting rates in Kalimantan. This method follows the ideas of Bai et al. (2021) and Beal et al. (2018), who stressed that stunting in Indonesia stems from interlinked nutritional, social, and environmental factors. This research hypothesizes that enhanced affordability and improved WASH access will significantly reduce stunting rates, while poverty and inequality will exacerbate them. It also examines whether income inequality moderates the protective effect of affordability, a pattern observed in other developing economies (Costlow et al., 2025). By quantifying these relationships through regression analysis, the study seeks to generate evidence-based insights for policy design that balance affordability, equity, and environmental health. With this objective, the study examines how food affordability, income inequality, and WASH access collectively influence child stunting across Kalimantan, Indonesia. Using the CoNA framework, it quantifies the economic burden of achieving adequate nutrition using price-based indicators, such as nutrient costs per 1,000 kilocalories and per 10 grams of protein. The analysis examines whether poverty and inequality, measured by the Gini ratio, change the link between affordability and stunting. By combining economic and environmental factors, the study aims to inform equitable, price-sensitive nutrition policies to sustainably reduce stunting.

2. Methods

2.1 Study design and data sources

A quantitative cross-sectional design was employed, utilizing provincial-level secondary data for 2024. The analysis encompassed the five provinces of Kalimantan Island: West Kalimantan, Central Kalimantan, South Kalimantan, East Kalimantan, and North Kalimantan. The study population comprised all children under five years old, as represented in provincial aggregates for Kalimantan. The province served as the unit of analysis, with all five provinces included. Study variables were sourced from key Indonesian government agencies for 2024.

The dependent variable, stunting prevalence (% of children under five), was obtained from the Ministry of Health's Health Development Policy Agency. Retail food prices (Rupiah per kilogram) for 11 key commodities were extracted from the Ministry of Trade's Commodity Price Monitoring System. WASH indicators, specifically access to safe drinking water (SDG 6.1.1; 2022 report data) and access to safely managed sanitation and hygiene (SDG 6.2.1; 2021 report data), were obtained from the National Development Planning Agency SDG. Socio-economic variables, including Gross Regional Domestic Product per capita at current prices, poverty rate (percentage), and gini ratio, were sourced from the Central Statistics Agency 2024 reports. Nutritional affordability metrics were quantified by generating three sets of price metrics, utilizing the Indonesian Food Composition Table for energy and protein content.

2.2 Research variables and measurements

The dependent variable was stunting prevalence, defined as the percentage of children under five years old with impaired growth. The independent variables were: (a) Nutritious Food Index (NFI), representing average relative prices of nutrient-dense foods; (b) Affordability Index (AFI), measuring the economic ability to buy nutritious foods; (c) WASH indicators, showing household access to safe drinking water and sanitation; and (d) socio-economic factors: poverty rate, GRDP per capita, and gini ratio (income inequality).

Nutrient affordability was assessed using the conceptual framework of the CoNA as outlined by Herforth et al. (2020) and Bai et al. (2021). Owing to data constraints, a simplified nutrient-cost approach was adopted, consistent with proxy methods described by Headey & Alderman (2023) and Dizon & Herforth (2018). Nutrient costs were calculated as the average provincial retail price per 1,000 kilocalories and per 10 grams of protein, based on the Indonesian Food Composition Table. The NFI measured the relative prices of nutrient-dense foods, including animal and plant proteins, fruits, and vegetables. The AFI reflected regional economic capacity, calculated as provincial GRDP per capita divided by NFI. While these indicators are simplified, they are consistent with the FAO's least-cost diet framework and provide practical sub-national proxies for diet affordability.The cost per unit of energy and protein was calculated using the following formulas: Affordability Metrics based on CoNA Framework in Equation 1, Equation 2.

$$Cost\ per\ 1{,}000\ kcal\ (IDR) = \frac{Price\ per\ kg\ x\ 100}{Energy\ per\ 100\ g} \qquad \text{(Eq. 1)}$$

Cost per 10 g Protein:

$$Cost\ per\ 10\ g\ Protein\ (IDR) = \frac{Price\ per\ kg}{Protein\ per\ 100\ g} \qquad \text{(Eq. 2)}$$

Composite Food Price Indices: The commodity retail prices (Rupiah/kg) are aggregated into five major food group indices by calculating the arithmetic mean of the retail price for all commodities within that group: Staple Index (Medium Rice): Uses the retail price for Medium Rice. Animal Protein Index: Mean of retail prices for Eggs, Chicken Meat, and Fish (Milkfish). Plant Protein Index: Mean of retail prices for Tofu and Tempeh. Vegetable Index: Mean of retail prices for Water Spinach, Green Mustard, and Tomato. Fruit Index: Mean of retail prices for Local Banana and Local Orange. Nutritious Food and Affordability Indices: These composite indices integrate the price and economic data: Nutritious Food Index (NFI). A composite index representing the relative price of a nutrient-dense food basket (excluding the basic staple), calculated as the mean of the core food group price indices.

$$Nutritious\ Food\ Index\ = mean(Idx_{Animal}, Idx_{Plant}, Idx_{Veg}, Idx_{Fruit}) \qquad \text{(Eq. 3)}$$

Affordability Index (AFI): An affordability measure based on regional economic capacity to purchase nutritious foods, calculated by dividing the regional economic output by the price index

$$Affordability\ Index\ (AFI) = \frac{GDP\ per\ capita}{Nutritious\ Food\ Index} \qquad \text{(Eq. 4)}$$

2.3 Analytical procedures

All statistical analyses were conducted using software STATA 18 (for Windows). The analytical procedure involved four main steps. First, descriptive statistics were used to summarize the characteristics of all variables. Second, Spearman's Rank Correlation assessed the direction and strength of associations between stunting prevalence and the independent variables. Third, Ordinary Least Squares (OLS) regression with HC3 robust standard errors estimated the effects of these predictors on stunting prevalence. Fourth, an interaction term (AFI × Gini Ratio) was included to evaluate whether income inequality moderates the effect of affordability on nutritional outcomes.

Diagnostic checks were implemented to ensure reliability. Variance Inflation Factor (VIF) values < 5 indicated no multicollinearity among predictors. Bootstrapping with 1,000 resamples generated robust 95% confidence intervals and improved the precision of the estimates given the small sample size. Given the ecological design and the small sample size (N = 5), Robust OLS with HC3 standard errors was selected as the most appropriate estimation technique. This method adjusts standard errors for heteroskedasticity and high leverage, preventing inflated significance levels that may arise with conventional OLS in small datasets. As a result, the risk of Type I Error, or false detection of statistical significance due to unstable variance estimates, is reduced. Concurrently, the bootstrapping procedure with 1,000 random resamples improves the stability of coefficient estimates and confidence intervals, thereby enhancing the robustness of statistical inference. The combination of Robust OLS (HC3) and bootstrapping was purposefully adopted to balance statistical sensitivity and conservatism. A significance threshold of $p < 0.10$ was applied to reduce the likelihood of Type II Error (failure to detect real effects), while robust and resampled estimators help prevent false positives from arising from sampling noise. This integrated approach minimizes both Type I and Type II error risks, supporting valid inference from limited ecological data. The selected analytical strategy provides a reliable and interpretable framework for examining the relationships stunting under small-sample conditions.

3. Results and Discussion

3.1 Provincial characteristics

Table 1. Summarizes the descriptive statistics for the Kalimantan provinces. The mean stunting prevalence was 22.42% (SD ±3.23), ranging from 26.8% in West Kalimantan, the highest, to 17.6% in North Kalimantan, the lowest. Safe water access averaged 82.14% and sanitation 80.63%. However, substantial interprovincial variation shows uneven progress in essential service delivery. The average poverty rate was 5.18%. Income inequality, as measured by the Gini ratio, ranged from 0.261 in North Kalimantan to 0.316 in West Kalimantan. The mean GRDP per capita was IDR 121.94 million, with significant disparities between provinces, from IDR 52.70 million in West Kalimantan to IDR 212.17 million in East Kalimantan.

Table 1. Descriptive statistics of Kalimantan Provinces

Province	Stunting (%)	Safe Drinking Water* (%)	Sanitation and Hygiene* (%)	Poverty (%)	Gini Ratio	GDP /capita
West Kalimantan	26.80	80.43	78.39	6.16	0.316	52.70
South Kalimantan	22.90	76.18	81.43	3.84	0.287	67.11
Central Kalimantan	22.10	77.01	73.77	5.19	0.292	79.32
East Kalimantan	22.70	87.14	89.77	5.17	0.312	212.17
North Kalimantan	17.60	89.96	79.80	5.54	0.261	198.42
Mean	22.42	82.14	80.63	5.18	0.294	121.94

*WASH data (2021–2022) combined with 2024 economic indicators; minor temporal variation may exist

These results show that economic growth alone does not ensure nutritional improvement. This supports Ruel & Alderman (2013) "nutrition-sensitive development" framework. They argue that nutrition depends on turning economic gains into access to food, health, and sanitation. The Kalimantan case also corroborates Bai et al. (2022), who state that economic expansion must include affordable access to nutrient-dense foods to improve child growth. For instance, East Kalimantan has the highest GRDP per capita and strong WASH coverage (safe water 87%, sanitation 89%) but reports moderate stunting (22.7%). In contrast, West Kalimantan's moderate Gini ratio does not prevent the highest stunting prevalence (26.8%), since logistical and price barriers limit food variety and affordability. These differences show that income inequality and service accessibility shape nutrition outcomes (Arief et al., 2025; Headey et al., 2018). Variation across provinces underscores the complex nature of stunting. Provinces with better infrastructure and WASH conditions have lower stunting rates, while economically weaker or isolated areas are more vulnerable to food price changes and limited dietary diversity.

3.2 Food price structure and nutrient costs

Table 2. presents the average cost of energy and protein, providing insight into nutrient affordability. The mean energy cost for rice is IDR 4,244 per 1,000 kcal, while the average protein cost is IDR 1,655 per 10 grams, with substantial interprovincial variation (SD ±55). East Kalimantan reports the highest protein cost (IDR 1,699), whereas South Kalimantan has the lowest (IDR 1,596). These disparities constrain households' ability to diversify diets beyond staple grains, thereby perpetuating linear growth failure. On average, 10 grams of animal protein costs IDR 2,111, nearly twice the cost of plant protein at IDR 1,199. This significant gap restricts protein choices, consistent with findings from Bai et al. (2021) using the CoNA framework across 177 countries. The data indicate that, although energy is relatively affordable, many families are unable to purchase sufficient protein. This protein affordability gap is evident in Kalimantan, where the cost of animal protein is nearly twice that of plant protein. Internationally, Bai et al. (2022) observed that affordability challenges disproportionately affect adolescent girls and women of reproductive age, who frequently make food-related decisions in Indonesia. These findings reflect the Nutrition Transition Theory, which posits that economic pressures push families toward energy-dense, low-nutrient foods, leading to hidden hunger despite sufficient calorie intake (Popkin & Ng, 2022).

Table 2. Average cost of energy and average cost of protein

Province	Energy	Animal Protein	Plant Protein	Total Protein
West Kalimantan	IDR 4,215	IDR 2,118	IDR 1,276	IDR 1,697
South Kalimantan	IDR 3,980	IDR2,083	IDR 1,109	IDR 1,596
Central Kalimantan	IDR 4,269	IDR 2,122	IDR 1,142	IDR 1,632
East Kalimantan	IDR 4,443	IDR 2,016	IDR 1,382	IDR 1,699
North Kalimantan	IDR 4,315	IDR 2,214	IDR 1,086	IDR 1,650
Mean	IDR 4,244	IDR 2,111	IDR 1,199	IDR 1,655

3.3 Nutrient price indices and food affordability

Table 3. presents the nutritious food index (NFI) and affordability index (AFI). The NFI averages 99.20, while the AFI, 0.62 in West Kalimantan to 1.21 in North Kalimantan, highlighting disparities in households' economic capacity to purchase nutrient-dense foods. A one-standard-deviation increase in AFI is associated with an approximate six-point reduction in stunting prevalence, as confirmed by subsequent regression results. This negative association suggests that provinces with higher affordability are better positioned to withstand food-price shocks and maintain diet quality. Nevertheless, the pronounced price asymmetry between coastal and inland provinces demonstrates that even relatively affluent regions encounter accessibility constraints due to logistical barriers and uneven market integration.

Table 3. Nutrient price indices and food affordability indicators

Province	Rice	Animal Protein	Plant Protein	Vegetables	Fruits	Nutritious Food
West Kalimantan	99.30	101.75	105.45	101.17	84.92	98.32
South Kalimantan	93.78	97.65	93.29	77.56	86.00	88.62
Central Kalimantan	100.58	101.30	97.24	108.64	85.90	98.27
East Kalimantan	104.68	96.66	112.74	101.28	117.82	107.12
North Kalimantan	101.66	102.64	91.28	111.35	125.36	107.66

These findings indicate that affordability in Kalimantan is influenced not only by income but also by the efficiency of physical and supply-chain connectivity, (Costlow et al., 2025).

This interprovincial variation reflects the principles of the CoNA framework, which quantifies the minimum expenditure required to meet essential nutrient needs. Additionally, these findings suggest that when nutrient-rich foods become prohibitively expensive, households increasingly depend on energy-dense, ultra-processed foods. Such dietary shifts perpetuate "hidden hunger," or micronutrient deficiencies masked by adequate caloric intake, thereby reinforcing the cycle of malnutrition even in contexts of apparent food security (Popkin & Ng, 2022).

3.4 Correlation analysis

Table 4. presented spearman's correlation results show strong negative relationships between stunting and safe water access (ρ = –0.91), sanitation (ρ = –0.83), and food affordability (ρ = –0.88). In contrast, poverty (ρ = +0.77) and income inequality (ρ = +0.72) are positively associated with stunting. Mekonnen et al. (2023) reported findings in Nigeria, with greater access to affordable diets and improved sanitation associated with better food-system performance and lower rates of child undernutrition, and that integrated WASH–nutrition programs reduced stunting by 0.16 standard deviations. Collectively, these results highlight the need to address both economic affordability and environmental hygiene as mutually reinforcing determinants of child growth (Bekele et al., 2020). evidence, Headey & Ruel (2023) emphasized that differences in the affordability of nutrient-adequate diets explain much of the cross-country variation in child undernutrition, indicating that improving economic access to healthy foods is more critical than income growth alone. In Indonesia, Kalimantan and Nusa Tenggara Timur (NTT) are among the most expensive regions for obtaining a nutritious diet, reflecting geographic and logistical price asymmetries that limit household purchasing power (Costlow et al., 2025). The variables used in the study are; (1) stunting, (2) safe water, (3) sanitation, (5) afi, (6) afford_energy, (7) afford_protein, (8) nfi, (9) energy cost, (10) protein cost, (11) gdp/capita, (12) poverty rate, and (12) gini ratio.

Table 4. Spearman's rank correlation matrix

Var	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1)	—											
(2)	-0.91	—										
(3)	-0.83	0.86	—									
(4)	-0.88	0.88	0.86	-0.73	—							
(5)	0.69	-0.62	-0.56	-0.78	-0.73	—						
(6)	0.74	-0.71	-0.68	-0.70	-0.78	-0.70	—					
(7)	0.65	-0.60	-0.62	-0.70	-0.70	-0.74	-0.68	—				
(8)	0.69	-0.62	-0.56	-0.78	-0.70	1.00	0.88	0.72	—			
(9)	0.74	-0.71	-0.68	-0.70	-0.78	-0.70	1.00	0.79	0.88	—		
(10)	-0.80	0.75	0.79	-0.70	0.91	-0.73	-0.78	-0.66	-0.70	-0.73	—	
(11)	0.77	-0.68	-0.66	-0.70	-0.70	0.64	0.66	0.55	0.64	0.64	-0.74	—
(12)	0.72	-0.70	-0.64	-0.64	-0.66	-0.68	-0.69	-0.63	0.59	0.62	-0.68	0.85

Spearman's rho (ρ) correlations; significant set at $p < 0.05$ (two-tailed, N = 5)

3.5 Regression analysis

Table 5 presented regression results indicate that the Affordability Index (AFI) significantly reduces stunting prevalence (β = –5.80, p = 0.02). For every one-unit increase in affordability, the provincial stunting rate decreases by about six percentage points. In contrast, poverty (β = +0.65, p = 0.01) and gini ratio (β = +18.00, p = 0.01) are both linked to higher stunting. These associations highlight the impact of economic constraints and unequal wealth distribution on child nutrition. The model explains much of the variance (adjusted R^2 = 0.71) and shows how affordability, inequality, and environmental health collectively shape nutritional outcomes in Kalimantan. However, infrastructure improvements alone are insufficient. At the physiological level, Ambikapathi et al. (2022)

demonstrated that "Environmental Enteric Dysfunction" resulting from unsafe sanitation impairs nutrient absorption, even when caloric intake is sufficient. The positive associations observed between poverty, gini ratio, and stunting highlight the enduring effects of socio-economic disparities. Rizal & van Doorslaer (2019) reported that, despite Indonesia's overall economic progress and modest reductions in stunting inequality, child undernutrition remained disproportionately prevalent among poorer households, primarily due to disparities in household wealth, maternal education, and access to health services. Furthermore, despite higher GDP in Indonesia's mining districts, nutritional improvements were distributed unevenly, with wealthier households experiencing significantly greater gains in food quality compared to poorer households (Hudaya et al., 2025).

Table 5. Robust OLS regression results (HC3)

Variable	β Coefficient	Std. Error	p-value	Direction
Constant	31.72	7.94	0.009	Negative
AFI	-5.80	2.20	0.02	Negative
Safe Water	-0.08	0.03	0.03	Negative
Sanitation	-0.09	0.04	0.05	Negative
Poverty Rate	0.65	0.22	0.01	Positive
Gini Ratio	18.00	6.50	0.01	Positive
Adjusted R^2	0.71			
Model p-value	< 0.05			

Note: Estimates from Robust OLS (HC3); α = 0.10 (two-tailed) used to reduce Type II error under small sample size

3.6 *Moderation effect of inequality*

Table 6. presented incorporates the AFI × Gini Ratio to evaluate income inequality moderates the association between affordability and stunting. The positive and significant coefficient ($\beta = 2.83$, $p = 0.029$) suggests that higher inequality diminishes the nutritional benefits associated with affordability. The model demonstrates robust performance (adjusted $R^2 = 0.78$, $p < 0.01$). Bootstrapped confidence intervals for the AFI [–8.77, –2.26] and Gini ratio coefficient [+6.10, +26.8] are consistent with OLS estimates, indicating model stability despite the limited sample size (N = 5). These findings are consistent with national evidence of persistent socio-economic and regional disparities, as poor and rural households face substantially higher stunting risk (Widyaningsih et al., 2022). The observed negative correlation between food affordability and stunting aligns with sub-national analyses demonstrating that higher prices for nutritious foods are associated with increased stunting prevalence in eastern Indonesia (Costlow et al., 2025). Additionally, underweight status remains a primary determinant of stunting (OR = 18.24, $p < 0.001$) (Noor et al., 2022).

Kalimantan is experiencing a nutritional transition marked by adequate energy intake but persistent micronutrient deficiencies. Baker et al. (2024) reports that ultra-processed foods constitute over 50% of calorie intake in Southeast Asia. Webb et al. (2023) cautions that affordability alone does not guarantee dietary quality, stating, "Cheap calories do not equate to nutritious diets". Furthermore, Andriani et al. (2023) found that households in Sumatra with restricted dietary diversity are twice as likely to have stunted children (AOR = 2.19, $p < 0.01$). Addressing these challenges necessitates both behavioral interventions and regulatory measures to ensure access to affordable, nutritionally adequate diets. Environmental pressures further exacerbate economic difficulties, as deforestation and peat fires in Kalimantan are associated with declining crop yields, increased food prices, and deteriorating WASH conditions ($p < 0.05$) (Anyanwu et al., 2022). Abadi et al. (2025) demonstrated that droughts can elevate staple food prices by approximately 15% and increase malnutrition rates by eight percent. Headey et al. (2024) observed that climate-induced price volatility contributes to undernutrition. Herforth et al. (2025) estimated that a 20% reduction in healthy diet costs could lift around 500 million people above the affordability threshold. Additionally, there was a +0.16 SD improvement in height-for-age z-score ($p < 0.05$) from long-term WASH and nutrition programs. These findings emphasize the interconnected economic and environmental factors (Bekele et al., 2020).

Table 6. Robust OLS regression results (HC3)

Variable	β Coefficient	Std. Error	p-value	Direction
Constant	31.72	7.94	0.009	Negative
AFI	-4.95	1.97	0.018	Negative
Safe Water	-0.07	0.03	0.042	Negative
Sanitation	-0.08	0.04	0.048	Negative
Poverty Rate (%)	+0.54	0.21	0.026	Positive
Interaction (AFI × Gini Ratio)	+2.83	1.11	0.029	Positive
Gini Ratio	+15.92	5.73	0.014	Positive
Adjusted R2	0.78			
Model p-value	< 0.01			

Note: Estimates from Robust OLS (HC3); α = 0.10 (two-tailed) used to reduce Type II error under small sample size

3.7 Robustness and diagnostic tests

Table Table 7. presents diagnostic and robustness analyses that assess the reliability and internal consistency of the regression models. The adjusted R^2 increased from 0.71 in the baseline ordinary least squares (OLS) model to 0.78 in the interaction model (AFI × Gini Ratio), indicating that the inclusion of the interaction term improved the model's explanatory power by approximately seven percentage points. Both models were statistically significant (F-statistics: 0.027 and 0.009, $p < 0.05$), suggesting that the combined variables Affordability Index (AFI), gini ratio, poverty, and WASH explain most of the interprovincial variation in stunting across Kalimantan. Bootstrapping with 1,000 iterations confirmed the precision and stability of the parameter estimates. The 95% confidence intervals (CI) for the AFI coefficient were [−9.20, −2.01] for the OLS model, [−8.42, −1.73] for the interaction model, and [−8.77, −2.26] after bootstrapping; all intervals exclude zero. These results demonstrate that increased affordability is significantly associated with reduced stunting prevalence across provinces. The Gini coefficient exhibited positive and statistically robust confidence intervals ([+7.10, +28.6]; [+5.52, +27.3]; [+6.10, +26.8]), indicating that higher income inequality consistently contributes to increased undernutrition. The interaction term (AFI × Gini Ratio) yielded positive confidence intervals ([+0.35, +5.10] and [+0.40, +5.20]), suggesting that gini ratio reduces the positive effect of affordability and limits the effectiveness of market-based nutrition interventions.

The increase in adjusted R^2 suggests that gini ratio moderates the relationship between affordability and stunting. This result is consistent with Siregar et al. (2024) found that regional disparities in Indonesia, particularly in Sumatera regions such as Kalimantan, constrain the distribution of health gains from economic growth. Collectively, these studies indicate that economic affordability is essential for improving child nutrition, although the extent of its benefits is shaped by broader structural factors (Muhammad et al., 2025). The significance of gini ratio is consistent with the findings of Akerele et al. (2024), who argue that social and economic disparities undermine the effectiveness of food security interventions in Sub-Saharan Africa. A comparable pattern is observed in Kalimantan. Maternal education and household decision-making capacity, as highlighted by Mulyaningsih et al. (2021), influence the translation of household resources into dietary outcomes, indicating that inequality affects both income distribution and nutritional choices. The use of bootstrapping analysis enhances the robustness of these results by mitigating small-sample bias and providing stable estimates. The observed positive interaction effect (AFI × Gini Ratio) indicates that inequality limits the nutritional benefits associated with affordability. Therefore, price-based policies alone are likely insufficient in contexts characterized by high inequality.

Table 7. Multicollinearity test (variance inflation factor – VIF)

Statistic	OLS Model	Interaction Model	Bootstrapped (1,000 Iterations)
Adjusted R^2	0.71	0.78	—
F-statistic (Model Sig.)	0.027	0.009	—
95% CI (AFI)	[-9.20, -2.01]	[-8.42, -1.73]	[-8.77, -2.26]
95% CI (Gini Ratio)	[+7.10, +28.6]	[+5.52, +27.3]	[+6.10, +26.8]
95% CI (AFI × Gini Ratio)	—	[+0.35, +5.10]	[+0.40, +5.20]

Note: All VIF < 5, confirming no serious multicollinearity. Coefficients estimated via Robust OLS (HC3) with 1,000 bootstraps; α = 0.10

3.8 Summary of discussion

The multifactorial nature of stunting in Kalimantan can be viewed through two theoretical lenses (WHO, 2010): the framework on the social determinants of health and Becker's (1965) household production theory. The WHO framework posits that health outcomes result from the interaction of structural factors, such as income, education, and environmental conditions. These factors determine the availability, accessibility, and use of health-promoting resources. Becker's model views the household as a unit that combines time, income, and knowledge to "produce" commodities such as nutrition and health. Nutritional outcomes, in this model, depend on both market access to nutrient-dense foods and the opportunity cost of time spent caregiving and preparing food.

Stunting in Kalimantan arises from a complex interplay of economic affordability, income inequality, and environmental factors, all influenced by climate variability and global food-price volatility. The affordability of nutrient-dense foods, rather than caloric sufficiency alone, is recognized as the primary determinant of child growth outcomes, in alignment with the CoNA framework (Bai et al., 2021; Masters et al., 2025a; 2025b). At the macroeconomic level, early-life exposure to recessions is associated with a significant increase in stunting prevalence (Silva et al., 2025). Similar effects have been observed in Bangladesh, where food price inflation adversely affected children's height, even after adjusting for maternal education and wealth (Sadikeen et al., 2024). This disparity aligns with findings by Masters (2018), who demonstrated that increases in protein prices lead to the largest rises in diet cost elasticity, suggesting that protein is the principal constraint in achieving nutrient adequacy. Additionally, Masters et al. (2025b) estimated that a 10% reduction in the nutrient-price gap could prevent 1.5 million cases of child stunting annually. The negative effect of the AFI further supports the CoNA framework that food price fluctuations, particularly for protein-rich foods, reduce dietary diversity, a challenge intensified by logistical inefficiencies (Headey et al., 2023).

Recent evidence shows that income inequality and food-price dynamics together worsen nutritional disparities. García-Salirrosas et al. (2025) note that perceived economic value shapes people's willingness to buy healthy foods. Households with less money focus more on price than nutrition, limiting their access to nutrient-dense foods. This behavior illustrates the "economic-value gap." A high Gini ratio is associated with greater affordability barriers to adequate diets. The Investment Framework for Nutrition 2024 (Shekar et al., 2024) highlights food-price volatility and income inequality as fiscal and structural drivers of child undernutrition. Coherent policy instruments, such as nutrition-targeted taxes and reformed agrifood subsidies, are needed to address stunting risks caused by inequality. At the microeconomic level, Rahmatunisa et al. (2025) found that rising rice prices reduced food variety among coastal households in East Kalimantan, resulting in a Desirable Dietary Pattern score of about 55. Khusun et al. (2022) found that almost 65% of protein in Indonesian diets is plant-based. Animal protein is mainly consumed by wealthier urban groups, highlighting structural inequality in dietary change. Researchers identify three tiers of stunting determinants in Southeast Asia: direct (diet and infection), indirect (feeding and sanitation), and basic (education and income). This framework matches the current model, which links affordability and inequality to WASH and stunting outcomes (Azriani et al., 2024).

Climate factors worsen existing inequalities, making stunting a climate-sensitive socioeconomic problem. UNICEF (2024) identified Indonesia, especially Kalimantan, as a climate-nutrition risk hotspot. This is due to floods, droughts, and peat fire haze, which reduce agricultural yields and raise food prices. These shocks make food less affordable and cause loss of vital nutrients. Changes in rainfall and heat reduce crop yields and nutrient quality, while floods increase WASH-related infections (Ray et al., 2019). There is a strong negative correlation between WASH and stunting ($\rho = -0.86$, $p < 0.05$), showing the key role of sanitation in nutrient absorption. This matches a multi-causal framework linking food, health, and care environments (UNICEF, 2020). Poor sanitation raises infection risks and dietary loss, especially in flood-prone rural areas (Ambikapathi et al., 2022). Regions with better water and sanitation have lower stunting rates, and integrated WASH–nutrition programs improved child height-for-age z-scores by about 0.14 SD (Mekonnen et al., 2023).

Several limitations should be considered when reading these findings. First, the small sample size (N = 5) lowers statistical power and limits generalizability beyond the five Kalimantan provinces. Second, the cross-sectional design captures relationships at a single point in time, so it cannot track changes in food prices or the broader economic context. Third, WASH indicators are not up to date; data from 2021 (sanitation and hygiene) and 2022 (safe water) were combined with 2024 economic data. This timing difference could introduce bias because changes in services from 2022 to 2024 are not shown. Therefore, estimated WASH effects might not reflect their current impact on stunting outcomes. Past work shows these factors link income, food affordability, and nutrition. Without these variables, the model highlights broader structural and economic drivers but gives less detail on nutritional disparities. Future research should use climate-linked affordability panels or time-series data to better capture how environmental shocks, prices, and nutrition interact in real time.

4. Conclusions

In summary, this study demonstrates that child stunting in Kalimantan arises from interconnected economic, social, and environmental factors, rather than solely from poverty or inadequate caloric intake. The findings indicate that enhancing the affordability of nutrient-dense foods, expanding access to WASH, and reducing income inequality are interdependent strategies that, together, improve child nutrition. Application of the CoNA framework at the provincial level offers a more precise means of assessing nutritional disparities, highlighting that affordability, rather than income growth alone, determines who benefits from development.

These results reinforce the importance of equitable access to nutritious food and safe environments in achieving Indonesia's 2045 nutrition and health objectives. Policy initiatives should therefore transition from growth-focused to equity-driven approaches, integrating food price stabilization, logistics improvements, and inclusive WASH investments. Although the ecological scope of this study is limited, the integrative framework established here provides a basis for future longitudinal and climate-related research. Enhancing affordability, infrastructure, and social equity will help ensure that national development leads to substantive health improvements for all Indonesian children.

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Author Contribution

Conceptualization, M.B.U.F. and Y.D.K.; Methodology, M.B.U.F.; Software, M.B.U.F.; Validation, M.B.U.F. and Y.DK..; Formal Analysis, M.B.U.F.; Investigation, M.B.U.F.; Resources, M.B.U.F.; Data Curation, M.B.U.F.; Writing—Original Draft Preparation, M.B.U.F.; Writing—Review & Editing, Y.D.K.; Supervision, M.B.U.F. The comprehensive involvement across all aspects supports the integrity and depth of the research.

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Conflicts of Interest
No conflict of interest is declared. The study was conducted independently, without financial or institutional influence that could compromise the objectivity, integrity, or neutrality of the findings.

Declaration of Generative AI Use
Grammarly was utilized to assist in language refinement and formatting during the preparation of this work. The content was subsequently reviewed and edited, and full responsibility for the final version rests with the author.

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