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Predicting stunting incidence in Pidie, Indonesia using SEM-PLS and GIS: A multilevel analysis of determinants

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ABSTRACT

Stunting is a complex child health issue caused by poor nutrition, infections, and environmental factors. The Pidie District in Aceh, Indonesia, has been identified as a high-priority area for stunting intervention, with five sub-districts showing high prevalence rates. This study aims to identify the key determinants of stunting at the individual, household, and community levels and to develop a predictive model for stunting incidence in these areas. Structural Equation Modeling-Partial Least Squares (SEM-PLS) and Geographic Information Systems (GIS) were used to analyze the causal relationships and spatial distribution of stunting. Data were collected using a structured questionnaire and total sampling method, involving 988 mother-child pairs across Tangse (211), Tiro (46), Kembang Tanjong (321), Simpang Tiga (361), and Mutiara Timur (49). SEM-PLS results indicated that stunting is consistent with the Conceptual Childhood Stunting Model and the Social Determinants of Health (CSDH) framework, with the model explaining 73.2% of the variance in stunting cases (R^2 = 0.732). GIS mapping showed that Kembang Tanjong had the highest number of cases (184), while Tiro had the lowest (25). The main contributing factors were individual characteristics, household socioeconomic status, and community conditions. These findings suggest that targeted interventions addressing local risk factors, along with improvements in nutrition, healthcare access, and socioeconomic development, are essential to reduce stunting in the Pidie District.

1. Introduction

Health is a multidimensional state of well-being comprising physical, mental, spiritual, and social aspects, which enables individuals to lead productive lives in both social and economic domains. Despite notable advancements in public health nationally, disparities remain mainly influenced by socioeconomic status and geographical factors, with child health being a critical concern (Nurhasanah et al., 2024). Children under five are especially vital, as their growth and development significantly influence a nation's future trajectory. Therefore, prioritizing child health is essential for improving Indonesia's health outcomes. This emphasis is reflected in the National Medium-Term Development Plan (RPJM) 2020–2024, as well as in the strategic plan of the Ministry of Health, which underscores priority health issues such as maternal and child mortality, stunting management, disease prevention, and control, the Healthy Living Community Movement (GERMAS), and health system governance.

Stunting constitutes a significant public health challenge, primarily arising from inadequate nutrition and being shaped by various social determinants of health. Research has shown that exclusive breastfeeding plays a critical role in the prevalence of stunting (Elisia et al., 2023). Additionally, infectious diseases represent a significant risk factor contributing to stunting. Other investigations highlight that parental height, paternal education, and household income contribute to childhood stunting, suggesting a multifactorial origin influenced by genetics and socioeconomic conditions instead of being attributed solely to malnutrition (Supadmi et al., 2024). Given the multifaceted nature of stunting, a comprehensive intervention approach that addresses nutrition, infection control, parental education, and economic

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status is necessary. The implications of stunting transcend individual health outcomes, significantly affecting national development. Stunted children often experience cognitive and motor development delays, compromised immune responses, and increased vulnerability to non-communicable diseases (Ford and Stein, 2016; Roberts et al., 2022). Evidence has established a link between stunting and adverse educational outcomes, decreased future earning potential, and higher poverty rates, ultimately undermining national productivity and the quality of human capital (Rahmadiyah et al., 2024). Globally, approximately one-third of children under five are affected by stunting. Data from UNICEF, WHO, and the World Bank estimate that 159 million children in this age group are stunted, with the highest prevalence rates observed in Asia and Africa (Shekar et al., 2017). Regional data reflects disparities, with Oceania (38.1%), East Africa (35.6%), South Asia (33.3%), and Central Africa (32.1%) exhibiting the highest prevalence rates. Furthermore, 25% of stunted children are found in low-income countries, 66% in middle-income nations, and 8% in high-income countries (Ahmed et al., 2021).

Numerous studies, both globally and in the Indonesian context, have examined the determinants of stunting to identify effective interventions. Research conducted in Ethiopia identified several internal factors affecting stunting, such as the lack of breastfeeding and maternal body mass index (BMI), particularly in cases of overweight or obesity (Saleh et al., 2021). External factors influencing stunting encompass maternal employment status, higher household welfare levels (Li et al., 2020), and environmental factors such as residence in arid regions, low birth weight, and maternal underweight BMI (Akombi et al., 2017).

Emily et al. conducted a study exploring stunting risk factors among children under five in rural Guatemala. Their findings indicated that proper nutrition considerably mitigated the risk of stunting, as observed in 65.6% of malnourished children (Kragel et al., 2020; Gaston et al., 2022; Hossain et al., 2023). A similar investigation by Giao et al. (2019) focused on the prevalence of stunting and obesity in children aged 12 to 24 months who received vaccinations in Ho Chi Minh City (HCMC). This cross-sectional study recruited participants from 16 randomly selected health centers across eight districts, utilizing a height-for-age z-score ≤2 standard deviations (SD) to define stunting and a BMI z-score >+2 SD to classify overweight. The results demonstrated that the prevalence of overweight exceeded that of stunting among young children, indicating that urban childhood obesity is becoming an emergent public health challenge (Giao et al., 2019; Kusumawardani et al., 2020).

Stunting indicates chronic malnutrition, recurrent infections, and insufficient dietary quality. It is associated with delayed motor skills development, cognitive deficiencies, weakened immunity, and metabolic disorders. Stunted children are at an increased risk for adult obesity, cardiovascular diseases, and diminished productivity (Taslim et al., 2023). The Indonesian Ministry of Health has instituted a range of comprehensive interventions to combat stunting, including micronutrient supplementation, promoting breastfeeding, deworming, and providing nutritional education (Fristiwi et al., 2023; Erika et al., 2024; Escher et al., 2024).

Aceh Province continues to show some of the highest stunting rates in Indonesia. According to the 2021 Indonesian Nutrition Status Study, the five provinces with the highest prevalence of stunting are East Nusa Tenggara (37.8%), West Sulawesi (33.8%), Aceh (37.3%), West Nusa Tenggara (31.4%), and Southeast Sulawesi (30.2%) (Sufri et al., 2023). Although stunting rates in Aceh have declined, they remain significantly above the World Health Organization (WHO) target of below 20%. Within Aceh, Pidie District has shown a concerning trend in stunting rates, increasing from 36.2% in 2018 to 39.3% in 2021 (Hamdani et al., 2024). Despite the local government's endeavors, interventions have not yielded significant reductions in stunting prevalence, highlighting the need for more effective strategies to address this public health issue (Sufri et al., 2024).

This study's theoretical framework is rooted in the WHO's model on Childhood Stunting: Context, Causes, and Consequences (Stewart et al., 2013) alongside the Conceptual Framework on the Social Determinants of Health (CSDH) (WHO, 2010). These frameworks highlight how individual, household, and societal factors influence stunting. The CSDH identifies structural determinants such as parental education, poverty, birth spacing, and sociopolitical factors as primary contributors. These elements affect household situations and restrict access to proper nutrition and healthcare services, especially for mothers and children. Thus, a thorough understanding of these interconnected factors is vital for predicting and tackling stunting in the Pidie District.

Existing research on stunting utilizing Structural Equation Modeling-Partial Least Squares (SEM-PLS) and Geographic Information Systems (GIS) often concentrates on isolated variables. This study aims to investigate the determinants of stunting at the individual, household, and community levels in the Pidie District by employing SEM-PLS and SEM-GIS methodologies. The findings are expected to inform the development of a predictive model that can guide more effective and geographically tailored intervention strategies to reduce stunting prevalence in the region.

2. Methodology

2.1. Research design

This study adopts a quantitative research design that utilizes a cross-sectional approach. The measurement framework incorporates SEM-PLS and

GIS. SEM-PLS examines the relationships among latent variables, particularly stunting and its indicators, across three levels: Individual, household, and community (Sunardia et al., 2023). The structural model in SEM-PLS delineates the relationships between these latent variables, with hypothesis testing conducted utilizing the bootstrap method. Bootstrapping involves repeated resampling with replacement to estimate standard errors and assess model significance (Hair et al., 2021). The analysis yields path coefficients and R^2 values, the latter measuring the model's predictive strength and the extent to which exogenous latent variables explain endogenous latent variables.

The GIS component integrates spatial analysis by processing geographic data related to stunting prevalence. This includes mapping the locations of stunted children, delineating village-level stunting distributions, and identifying latitude-longitude coordinates to visualize spatial clustering of stunting cases. Data collection employs mobile GPS devices to ensure precision in spatial mapping. This GIS-based approach enhances the understanding of geographic disparities in stunting prevalence and supports the development of spatially informed intervention strategies (Shamsuddin et al., 2022).

2.2. Variable identification

In the present study, the variables under consideration are classified into independent and dependent categories. The independent variables include community (X1), household (X2), and individual (X3) factors. Community factors (X1) encompass socioeconomic status (M1), village geography (M2), availability of health services (M3), lifestyle choices (M4), and parental education levels (M5). Household factors (X2) comprise parenting practices (RT1), birth spacing (RT2), family income (RT3), and sanitation conditions (RT4). Individual factors (X3) incorporate body length (I1), body weight (I2), adherence to Clean and Healthy Living Behavior/Prilaku Hidup Bersih dan Sehat (CHLB/PHBS) (I3), age of the child (I4), prenatal examination (I5), exclusive breastfeeding practices (I6), dietary intake of the child (I7), gender of the child (I8), and incidence of infectious diseases (I9). The dependent variable identified is stunting (Y), which is analyzed across five sub-districts: Tangse (Y1), Kembang Tanjung (Y2), Mutiara Timur (Y3), Tiro (Y4), and Simpang Tiga (Y5).

Stunting represents a complex issue influenced by many factors (Ford and Stein, 2016; Kragel et al., 2020; Hamdani et al., 2024). Community-level determinants, including socioeconomic status, geographical attributes, and accessibility to health services, significantly affect child growth outcomes. Moreover, household characteristics such as parenting practices, birth spacing, economic status, and sanitation directly influence nutritional status and overall health. Individual attributes, including anthropometric measurements, health-related behaviors, age, prenatal care, breastfeeding practices, nutritional intake, gender characteristics, and susceptibility to infectious diseases, are critical when evaluating the risk of stunting. A comprehensive understanding of these variables within specific sub-districts enables the formulation of targeted interventions to address stunting effectively.

Research indicates that maternal nutrition and health behaviors significantly influence child growth outcomes. In particular, inadequate maternal nutrition during pregnancy is linked to intrauterine growth restriction, increasing the risk of stunting of offspring (Akombi et al., 2017; Hamdani et al., 2024). Additionally, environmental factors such as poor sanitation exacerbate the prevalence of stunting by increasing exposure to pathogens, subsequently leading to infections that impair nutrient absorption and growth. Addressing these determinants through comprehensive interventions at both community and household levels is crucial to reducing stunting rates effectively.

2.3. Population and sample

The study's population consists of children aged 12 to 36 months residing in five sub-districts of Pidie District, Aceh, Indonesia: Simpang Tiga, Tangse, Kembang Tanjung, Tiro, and Mutiara Timur. Nine hundred eighty-eight children (988) within this age range were identified across these sub-districts. The research utilized a total sampling method that included all 988 children and their mothers for anthropometric assessments. The distribution of respondents was as follows: Tangse sub-district included 211 participants, Tiro contained 46, Simpang Tiga had 361, Mutiara Timur recorded 49, and Kembang Tanjung accounted for 321 participants.

Total sampling, also called census sampling, entails the inclusion of every member of the population in the study. This approach eliminates sampling bias and allows for comprehensive data acquisition for analysis. It is particularly beneficial when the population size is manageable and complete enumeration is feasible. By adopting this method, the study guarantees that the findings accurately represent the entire population of children aged 12 to 36 months in the specified sub-districts, which enhances the validity and generalizability of the results. The precise distribution of respondents across the sub-districts permits a nuanced analysis of stunting prevalence and its correlating factors within each locality. This granularity aids in identifying area-specific determinants and supports the development of targeted interventions to address stunting in these communities.

2.4. Data collection technique

The primary data for this study were collected using anthropometric measurements of children with GEA-brand instruments for weight and height.

Body weight (BW) was measured with digital GEA-brand scales, accurate to 0.1 kg, and body length (BL) was measured with a GEA-brand microtome, accurate to 0.1 cm. These measurements were then recorded in the Community-Based Nutrition Recording and Reporting System (e-PPGBM) to determine the stunting status of the study subjects.

The research employed a structured questionnaire as the primary measurement instrument to evaluate attitudes, opinions, perceptions, and behaviors. Two distinct scales were utilized: The Guttman scale, which generates binary responses for unequivocal classification, and the Likert scale, which facilitates graded responses to assess participant perspectives. Primary data collection was executed by administering questionnaires alongside direct anthropometric assessments performed at community health centers (Puskesmas) or within the respondents' residences. The secondary data collection involved interviews to validate and elucidate specific findings derived from the primary measurement tools. Trained enumerators facilitated these interviews (Sufri et al., 2023).

The research data were obtained from the national BPS statistics regarding the prevalence of stunting and from the Decree of the Minister of National Development Planning Number 10/M.PPN/HK/02/2021. This decree relates to the designation of regencies and cities as Focus Locations for Integrated Stunting Reduction Interventions in 2022.

2.5. Data analysis

The collected data were processed using statistical software, involving editing, coding, data entry, and data cleaning stages. Quantitative analysis was performed in three distinct phases:

1. Univariate analysis: Frequency distribution tables were created for all independent variables (X), which included sociodemographic factors (M1), village geography (M2), health services (M3), lifestyle factors (M4), parental education (M5), parenting practices (RT1), birth spacing (RT2), family income (RT3), sanitation (RT4), body length (I1), body weight (I2), health behavior (I3), child age (I4), pregnancy examination (I5), exclusive breastfeeding (I6), child nutrition intake (I7), gender (I8), and infectious diseases (I9). The dependent variable under analysis was stunting (Y).
2. SEM-PLS: This multivariate statistical technique was utilized to evaluate the complex relationships among the variables. SEM-PLS is particularly advantageous due to its minimal requirements concerning measurement scales, sample sizes, and residual distribution (Riou et al., 2016). The analysis was conducted using SmartPLS version 3.2.0, released in 2024.
3. GIS application: GIS technology was employed to map and analyze geo-referenced data, which supports decision-making in public health planning and management. This methodology allowed for the spatial representation of factors contributing to stunting, offering insights into environmental and geographical influences on health outcomes (Shamsuddin et al., 2022).

This rigorous methodological framework ensured a thorough analysis of factors contributing to stunting, combining statistical modeling with spatial analysis to guide targeted interventions.

3. Results

3.1. Univariate data analysis of five sub-districts

The distribution of stunting cases across five subdistricts in Pidie District for 2024 is outlined in Table 1. The data demonstrate significant variations in the prevalence rates of stunting among the subdistricts. Mutiara Timur Subdistrict exhibited the highest prevalence, reported at 83.7%, and affected 41 children. The overall prevalence of stunting across these five subdistricts was 62.9%, highlighting a significant public health concern, particularly in areas with elevated rates, such as Mutiara Timur and Tangse. These findings underscore the necessity for more targeted interventions to address stunting, particularly in those subdistricts experiencing the most considerable burden. Further details on the data can be found in Table 1.

Additionally, the study evaluated maternal characteristics throughout the five subdistricts. Kembang Tanjong subdistrict was found to have the lowest socioeconomic status, with 28.3% of mothers categorized within this demographic. Detailed statistics on these characteristics are provided in Table 2. The study results indicate significant variations in health and nutrition-related factors among children across the five subdistricts. Further detailed data can be found in Table 3.

3.2. Data analysis based on SEM-PLS modeling

The structure of the SEM for the Tangse sub-district is presented following the bootstrapping procedure. Hypothesis testing was performed by comparing the t-count with the critical t-value sourced from the t-table. For the results to be deemed statistically significant, the t-count obtained from the bootstrapping test must surpass the one-tailed t-table value of 1.652107 at a significance level of 5%, or the p-value must be less than 0.05. The SEM structure is illustrated in Fig. 1.

The hypothesis test results in Table 4 show that socioeconomic factors, village geography, health services, lifestyle, and parental education significantly affect stunting incidence in the community. Conversely, household factors like parenting practices, birth spacing, family income, and sanitation do not substantially impact stunting.

Individual factors such as body height, weight, exclusive breastfeeding, nutrition, pregnancy check-ups, gender, age, CHLB, and infectious diseases significantly influence stunting. This confirms that individual characteristics are crucial to the stunting prevalence in the Tangse sub-district. The SEM model for the Tiro sub-district, post-bootstrapping, also indicates that household characteristics do not significantly affect stunting, while community and individual factors do contribute considerably to stunting prevalence (Supadmi et al., 2024). The structure of the SEM for Tiro is illustrated in Fig. 2.

Table 1: Percentage distribution of stunting in five sub-districts of Pidie district

Sub-district	n	Percentage	Average
Tangse	155	73.5%	
Tiro	25	54.3%	
Mutiara Timur	41	83.7%	62.9%
Simpang Tiga	165	45.7%	
Kembang Tanjong	184	57.3%	

Table 2: Data on maternal characteristics in five sub-districts of Pidie district

Variable	Category	Sub-district									
		Tangse		Tiro		Mutiara Timur		Simpang Tiga		Kembang Tanjong	
		n	%	n	%	n	%	n	%	n	%
Socio-economic (M1)	Well-off	49	23.2	16	34.8	11	22.4	140	38.8	128	39.9
	Sufficient	126	59.7	19	41.3	38	77.6	137	38.0	102	31.8
	Underprivileged	36	17.1	11	23.9	0	0	84	23.3	91	28.3
Village geographic (M2)	Highland	112	53.1	36	78.3	8	16.3	55	15.2	1	0.3
	Lowland	99	46.9	10	21.7	41	83.7	190	52.6	3	0.9
	Coastline	0	0	0	0	0		116	32.1	317	98.8
Health service (M3)	Good	94	44.5	21	45.7	19	38.8	107	29.6	121	37.7
	Poor	117	55.5	25	54.3	30	61.2	254	70.4	200	62.3
Lifestyle(M4)	Good	138	65.4	15	32.6	4	8.2	168	46.5	80	24.9
	Poor	73	34.6	31	67.4	45	91.8	193	53.5	241	62.3
Parent education (M5)	Elementary School	2	9	0	0	0	0	27	7.5	8	2.5
	Junior High School	23	10.9	12	26.1	11	22.4	34	9.4	44	13.7
	Senior High School	157	74.4	24	52.2	28	57.1	240	66.5	150	46.7
	Undergraduate	29	13.7	10	21.7	10	20.4	60	16.6	119	37.1
Parenting style (RT1)	Good	76	36.0	0	0	33	67.3	221	61.25	88	27.4
	Poor	135	64.0	46	100	16	32.7	140	38.8	233	72.6
Birth spacing (RT2)	>36 (ideal)	114	54.0	34	73.9	39	79.6	244	67.6	211	65.7
	< 36 non-ideal	97	46.0	12	26.1	10	20.4	117	32.4	110	34.3
Family income (RT3)	Moderate (>2,5 million)	64	30.3	11	23.9	17	34.7	95	26.3	195	60.7
	Low (<2,5 million)	147	69.7	35	76.1	32	65.3	266	32.4	126	39.3
Sanitation (RT4)	Good	37	17.5	12	26.1	6	12.2	128	35.5	62	19.3
	Fair	71	33.6	33	71.7	7	14.3	118	32.7	181	56.4
	Poor	103	48.8	1	2,2	36	73.5	115	31.9	78	24.3
Pregnancy check-up (I1)	Normal (>4x)	130	61.6	42	91.3	39	79.6	298	82.5	283	88.2
	Not normal (<4x)	81	38.4	4	8.7	10	20.4	63	17.5	38	11.8
CHLB (I5)	Good	82	38.9	22	47.8	0	0	173	47.9	178	55.5
	Poor	129	61.1	24	52.2	49	100	188	52.1	143	44.5

Table 3: Data on child characteristics in five sub-districts of Pidie district

Variable	Category	Sub-district									
		Tangse		Tiro		Mutiara Timur		Simpang Tiga		Kembang Tanjong	
		n	%	n	%	n	%	n	%	n	%
Exclusive breastfeeding (I2)	Exclusive	44	20.9	19	41.3	8	16.3	85	23.5	43	13.4
	Non-exclusive	167	79.1	27	58.7	41	83.7	276	76.5	278	86.6
Infectious diseases (I3)	Severe	40	19.0	6	13.0	6	12.2	42	11.6	153	47.7
	Mild	171	81.0	40	87.0	43	87.8	319	88.4	168	52.3
Child nutrition intake (I4)	Good	106	50.2	34	73.9	4	8.2	309	85.6	217	67.6
	Inadequate	85	40.3	4	8.7	44	89.9	42	11.6	79	24.6
	Poor	20	9.5	8	17.4	1	2.0	10	2.8	25	7.8
Child age (I6)	>3 years old	19	9.0	6	13.0	8	16.3	45	12.5	64	19.9
	< 3 years old	192	91.0	40	87.0	41	83.7	316	87.5	257	80.1
Gender (I7)	Male	115	54.5	24	52.2	29	59.2	207	57.3	178	55.5
	Female	96	45.5	22	47.8	20	40.8	154	42.7	143	44.5
Child weight (I8)	Normal	116	55.0	38	82.6	27	55.1	244	67.6	242	75.4
	Not normal	95	45.0	8	17.4	22	44.9	117	32.4	78	24.3
Child length (I9)	Normal	81	38.4	28	60.9	7	14.3	165	45.7	134	41.7
	Stunted	130	61.6	18	39.1	42	85.7	196	54.3	187	58.3

Table 4: Hypothesis testing based on the total effect in Tangse

Variable	Original sample	Sample mean	SD	T-statistics	P-value	Decision
Community ≥ stunting	0.470	0.442	0.169	2.777	0.006	Significant
Household ≥ stunting	0.306	0.281	0.179	1.710	0.088	Not significant
Individual ≥ stunting	-1.051	-1.028	0.202	5.204	0.000	Significant

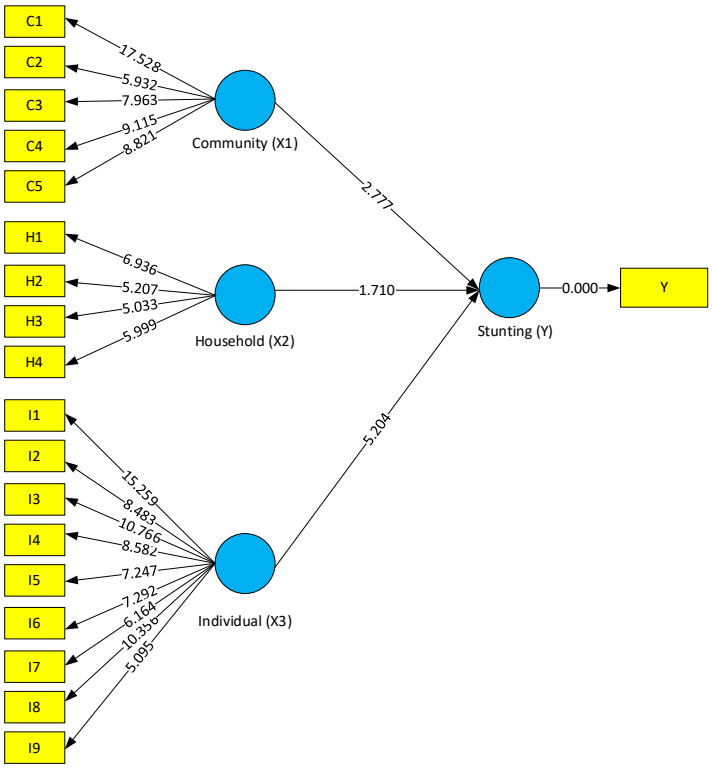

Fig. 1: The bootstrapping result of the SEM model in the Tangse sub-district

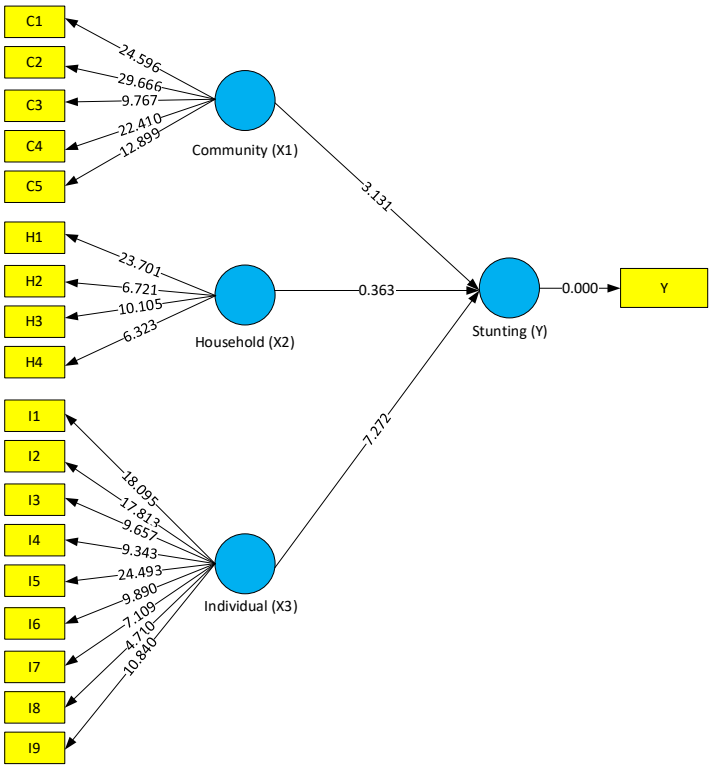

Fig. 2: The bootstrapping result of the SEM model in the Tiro sub-district

Table 5 shows that community factors—socioeconomic status, village geography, health services, lifestyle, and parental education—significantly impact stunting in the Tiro sub-district. This finding indicates that community characteristics are crucial to stunting in the area. In contrast, household factors like parenting practices, birth spacing, family income, and sanitation do not significantly influence stunting, suggesting they have minimal impact on rates in Tiro. Additionally, individual factors—body length, weight, exclusive breastfeeding, nutritional intake, prenatal check-ups, gender, child age, CHLB, and infections—also significantly affect stunting incidence, reinforcing their importance. Fig. 3 presents the SEM structural model post-bootstrapping. SEM analysis for the Mutiara Timur sub-district showed no significant links between community and household factors with stunting, while individual variables showed a significant relationship with outcomes.

Table 5: Hypothesis testing based on the total effect in Tiro

Variable	Original sample	Sample mean	SD	T-statistics	P-value	Decision
Community ≥ stunting	-0.821	-0.777	0.262	3.131	0.002	Significant
Household ≥ stunting	-0.107	-0.087	0.296	0.363	0.717	Not significant
Individual ≥ stunting	1.490	1.461	0.205	7.272	0.000	Significant

Table 6 findings reveal that community variables—socioeconomic status, village geography, health services, lifestyle, and parental education—do not significantly affect stunting incidence in the Mutiara Timur sub-district. Similarly, household factors like parenting practices, birth spacing, income, and sanitation do not significantly impact stunting. In contrast, individual factors, particularly body weight and height, significantly affect stunting, indicating their crucial role in outcomes. SEM analysis for the Simpang Tiga sub-district in Fig. 4 confirms that community variables do not contribute substantially to stunting incidence, while individual and household factors are significant influencers.

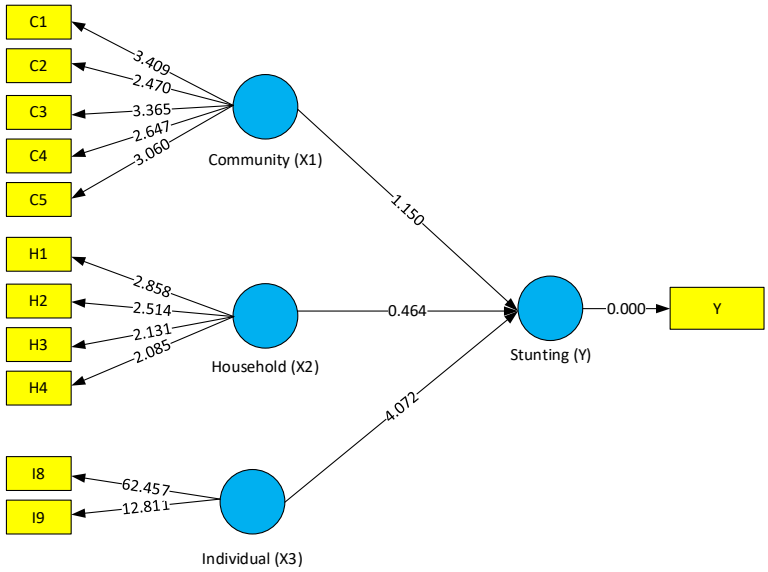

Fig. 3: The bootstrapping result of the SEM model in the Mutiara sub-district

Table 6: Hypothesis testing based on the total effect in Mutiara

Variable	Original sample	Sample mean	SD	T-statistics	P-value	Decision
Community ≥ stunting	0.239	0.174	0.208	1.150	0.251	Not significant
Household ≥ stunting	-0.092	-0.007	0.198	0.464	0.643	Not significant
Individual ≥ stunting	-0.404	-0.383	0.099	4.072	0.000	Significant

Table 7 illustrates that community variables—including socioeconomic factors, village geography, health services, lifestyle, and parental education—show no significant association with the prevalence of stunting in the Simpang Tiga sub-district. This conclusion is supported by a t-value of 1.115, less than the critical value of 1.649949, and a p-value of 0.265, exceeding the 0.05 significance threshold. Therefore, it is concluded that community factors do not significantly influence the incidence of stunting in this region.

Conversely, household variables, including parenting practices, birth spacing, family income, and sanitation, significantly impacted the prevalence of stunting. This is evidenced by a t-value of 5.928, which exceeds the critical value of 1.649949, and a p-value of 0.000 below the 0.05 threshold. Hence, it can be inferred that household factors significantly contribute to stunting incidence in the Simpang Tiga sub-district.

Individual factors—such as prenatal care, exclusive breastfeeding, the incidence of infectious diseases, nutritional intake, Clean and Healthy Behavior (PHBS), child age, weight, and body length—were also found to affect stunting rates significantly. The t-value of 5.160, greater than the critical value of 1.649949, alongside a p-value of 0.000, indicates that individual characteristics play a significant role in determining stunting outcomes in this sub-district.

Table 7: Hypothesis testing based on the total effect in Simpang Tiga

Variable	Original sample	Sample mean	SD	T-statistics	P-value	Decision
Community ≥ Stunting	0.043	0.050	0.039	1.115	0.265	Not significant
Household ≥ Stunting	0.473	0.467	0.080	5.928	0.000	Significant
Individual ≥ Stunting	0.431	0.432	0.084	5.160	0.000	Significant

Following the bootstrapping process, the SEM results for the Kembang Tanjong sub-district, as presented in Fig. 5, indicate that community, household, and individual factors all significantly influence the prevalence of stunting, with a p-value of less than 0.05.

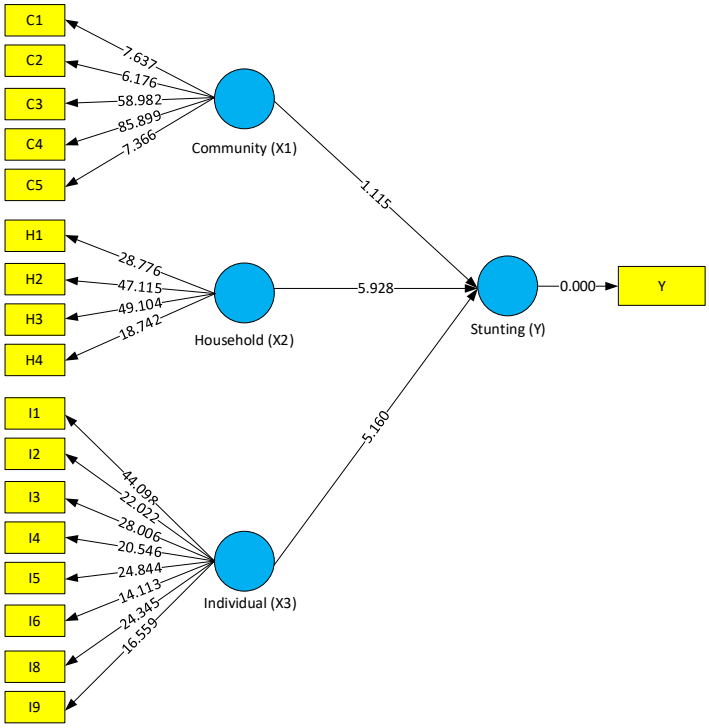

Fig. 4: The bootstrapping result of the SEM model in the Simpang Tiga sub-district

Table 8 shows that community factors like socioeconomic indicators, health services, lifestyle, and parental education do not significantly affect stunting incidence in Kembang Tanjong. In contrast, household factors such as parenting practices, birth spacing, family income, and sanitation significantly influence stunting, highlighting their impact. Additionally, individual factors like prenatal check-ups, exclusive breastfeeding, disease management, child nutrition, and demographic characteristics also significantly affect stunting, underscoring the importance of individual traits in this sub-district.

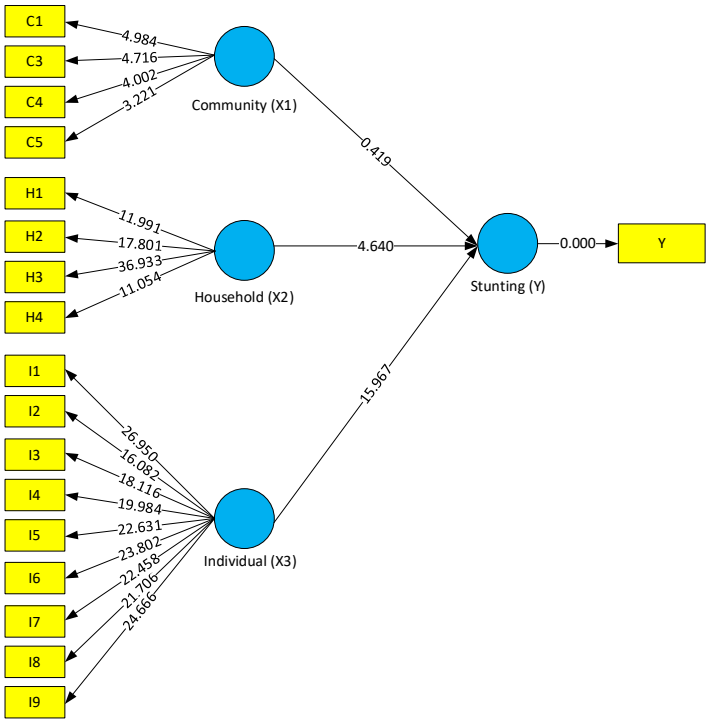

Fig. 5: The bootstrapping result of the SEM model in the Kembang Tanjong sub-district

Table 8: Hypothesis testing based on the total effect in Kembang Tanjong

Variable	Original sample	Sample mean	SD	T-statistics	P-value	Decision
Community ≥ stunting	-0.014	-0.007	0.033	0.419	0.675	Not significant
Household ≥ stunting	0.223	0.227	0.048	4.640	0.000	Significant
Individual ≥ stunting	0.726	0.723	0.045	15.967	0.000	Significant

3.3. Multi-group analysis (MGA) model of five sub-districts in Pidie district

The Bootstrapping SEM Multi-Group Analysis (MGA) of stunting in Pidie District shows that individual variables significantly affect stunting prevalence. The original sample value for these variables was -0.510, with a mean of -0.499. The T-statistic was 3.478, leading to a p-value of 0.001, indicating statistical significance. This suggests that improvements in individual factors reduce stunting incidence. Community variables also significantly influence stunting rates, with an original sample value of 1.022 and a mean (M) of 0.974. A T-statistic of 5.121 produced a p-value of 0.000, showing significance below 0.05. Increased community involvement correlates with lower stunting rates. Conversely, household factors, including parenting practices, birth spacing, income, and sanitation, showed no significant association with stunting. The original sample value for household variables was -0.062, with a mean of -0.017. The T-statistic of 0.254 resulted in a p-value of 0.800, indicating no significant impact on stunting outcomes. In summary, the model highlights the critical roles of community and individual factors in stunting rates while showing that household factors do not significantly affect stunting in Pidie. Detailed findings are in Table 9 and Fig. 6.

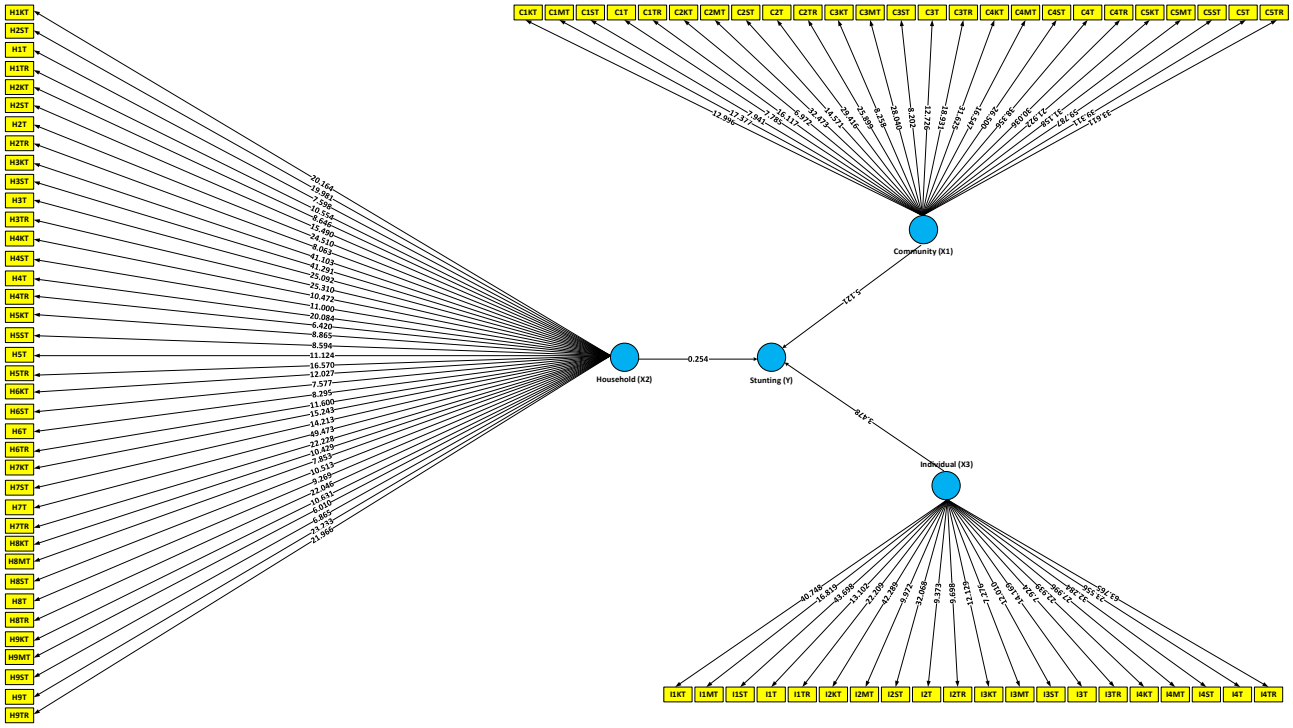

Fig. 6: Bootstrapping results of the MGA SEM model

Table 9: MGA modeling prediction of stunting incidence in Pidie District

Variable	Original sample	Sample mean	SD	T-statistics	P-value	Decision
Individual->Pidie	-0.510	-0.499	0.147	3.478	0.001	Significant
Community->Pidie	1.022	0.974	0.200	5.121	0.000	Significant
Household->Pidie	-0.062	-0.017	0.245	0.254	0.800	Not significant

The output from Smart PLS presented in Table 10 reveals an R Square (R^2) value of 0.732, corresponding to 73.2%. This indicates that the predictive model for the incidence of stunting in the Pidie District accounts for 73.2% of the variance observed in the factors contributing to the stunting region.

Table 10: R-squared value (combined results between exogenous and endogenous variables)

District	R-squared	R-squared adjusted
Pidie	0.732	0.722

3.4. The GIS result

Analysis of stunting in Pidie District's five sub-districts—Tangse, Tiro, Mutiara Timur, Simpang Tiga, and Kembang Tanjong—reveals significant disparities. Kembang Tanjong health center leads with 184 cases (57.3% of 321 respondents), followed by Simpang Tiga with 165 cases (45.7% of 361) and Tangse with 155 cases (73.5% of 211). Mutiara Timur has the fewest cases at 41 (83.7% of 49), while Tiro reports 25 cases (54.3% of 46) (Fig. 7A). Stunting distribution is visually mapped, showing red for affected areas and green for standard height. Pulo Seunong has 6 cases; Pulo Iee, Keubon Nilam, Paya Guci, Neubok Badeuk, Pulo Baro, Ule Gunong, Keude Tangse, and Pulo Masjid have 5. Beungga, Blang Bungong, Blang Dalam, Krung Meuriam, Peunalom I, and Blang Pandak report 4 each, while Alue Calong, Blang Malo, Pulo Kawa, Blang Jeurat, Blang Teungoh, Peunalom II, and Pulo

Masjid II report 3. Krueng Kekeuk and Ranto Panyang have 2 cases, and Lhok Keutapang reports 1 (Fig. 7B).

In Tiro, villages Rabo and Pulo Keunari have 5 cases; Peunadok has 4, and Meunasah Mancang, Pulo Tambo, Daya Kampong Baro, Lhok Igeueh, and Pulo Masjid have 2. Despite some villages showing no cases, early intervention remains essential for public health (Fig. 7C). In Mutiara Timur, Paloh Tinggi, and Mesjid Usi have the most cases at 5 each, while Mesjid Jeurat Manyang has 4. Cot Usi, Empeh, and Tong Weng report 3 each; other villages show 2 or fewer. Agriculture dominates the local economy in Mutiara Timur, which is further away from urban areas (Fig. 7D). Simpang Tiga displays notable stunting clusters, particularly in Peukan Sot and Ujong Gampong, with 4 cases. The overall rate is alarming, with about 50% of respondents exhibiting stunting signs (Fig. 7E). Lastly, Kembang Tanjong shows a consistent stunting distribution across villages, with Keude Ielebue, Pasi Lhok, Sukon, Jurong Mesjid, and Jemeurang reporting 2 to 3 cases each. Kembang Tanjong has the highest incidence at 184 cases (57.3%) (Fig. 7F).

SEM-PLS has effectively clarified the complex, multifaceted factors that impact health outcomes. For instance, Hasibuan et al. (2024) utilized a Bayesian Spatial Model with a Conditional Autoregressive (CAR) structure to examine stunting across 514 regencies and municipalities in Indonesia. Their analysis revealed that socioeconomic factors—including poverty, parental education, and sanitation access—significantly affect stunting rates in these regions. Similarly, Singrapati and Astuti (2024) conducted a spatial regression analysis in the Nusa Tenggara Archipelago and reported a Global Moran's I value of 0.420, indicating a moderate level of spatial autocorrelation. Their research highlighted early breastfeeding initiation and higher maternal educational levels as protective factors against stunting. Combining GIS with SEM-PLS adds analytical richness by placing statistical results within their geographic context. This integrated method allows a deeper understanding of how spatial disparities interact with individual and household determinants. This study's spatial distribution maps illustrated stunting clusters closely aligned with high-prediction sub-districts distinguished by SEM-PLS. For example, the sub-districts Simpang Tiga and Kembang Tanjong, which showed high predictive rates of stunting- 83% to 84%, respectively- were also flagged as spatial hotspots, underscoring the alignment between modeled statistical correlations and actual spatial distributions.

GIS mapping facilitated the visualization of micro-level clustering in specific villages, such as Keude Ielebue in Kembang Tanjong and Pulo Baro in Tangse. This finding highlights that structural and environmental factors—like access to healthcare services and reliance on agriculture—could strengthen the statistical results. These spatial insights improve the clarity of SEM-PLS outputs by placing high-loading indicators such as maternal education, exclusive breastfeeding, and sanitation infrastructure in recognizable geographic contexts. This combination allows policymakers to focus on high-risk areas and customize interventions based on demographic vulnerability and geographical marginalization (Alzahrani et al., 2024).

Despite national interventions, Aceh Province still faces unacceptably high stunting rates. According to the 2021 Indonesian Nutrition Status Study, Aceh ranked third in national stunting prevalence at 37.3%, trailing East Nusa Tenggara (37.8%) and West Sulawesi (33.8%) (Sufri et al., 2023). Recent years have shown slight improvements, yet the rates significantly exceed the WHO target of under 20%. Notably, in the Pidie District, stunting prevalence rose from 36.2% in 2018 to 39.3% in 2021 (Hamdani et al., 2024), indicating an urgent need to enhance current programs with integrated, evidence-driven, and geographically specific approaches (Sufri et al., 2024).

4. Discussion

Stunting represents a significant public health issue in Pidie, Aceh, Indonesia, predominantly influenced by individual and communal factors. A considerable proportion of mothers in this region do not provide exclusive breastfeeding for their toddlers, thereby heightening their vulnerability to various infections, both severe and mild. Deficiencies in nutritional intake and inadequate hygiene practices (Abdurrahman and Putra, 2024) further aggravate the prevalence of these infections (Sufri et al., 2023). Consequently, indices such as CHLB remain alarmingly low. The contextual factors of the community, including geographical and socioeconomic challenges, play a crucial role in the elevated rates of stunting reported in Pidie. The region's topographical features impede access to healthcare services and nutritious foods, while local cultural practices often deprioritize the nutritional needs of children. These challenges adversely affect children's growth and development, compounded by the region's unfavorable economic conditions (Ayuningtyas et al., 2022). Therefore, health professionals, community leaders, and parents must collaborate to enhance lifestyle practices, advocate for improved financial management, and adopt innovative strategies to promote children's well-being, mitigate stunting, and encourage healthier populations (Sufri et al., 2024).

Despite the recognition of the factors contributing to stunting and the guidance provided by healthcare professionals, a significant number of parents fail to care for their children under the age of five adequately. Even among parents with at least secondary education, outdated parenting practices inherited from previous generations often prevail. This persistence of traditional methods, which may include detrimental habits passed down, significantly impacts the quality of childcare today,

hindering efforts toward eliminating stunting in future generations. This observation aligns with findings from previous research, reinforcing the notion that internal and external factors contribute to stunting. Various demographic factors—including parental education, place of residence, employment status, and hygiene practices (Abdurrahman and Putra, 2024)—substantially influence stunting (Vaivada et al., 2020). Furthermore, research has substantiated a significant correlation between exclusive breastfeeding and stunting rates, underscoring that exclusive breastfeeding is critical for optimal growth, developmental progress, and overall health in children, as breast milk sufficiently meets a baby's nutritional requirements from birth to 24 months (Vilcins et al., 2018).

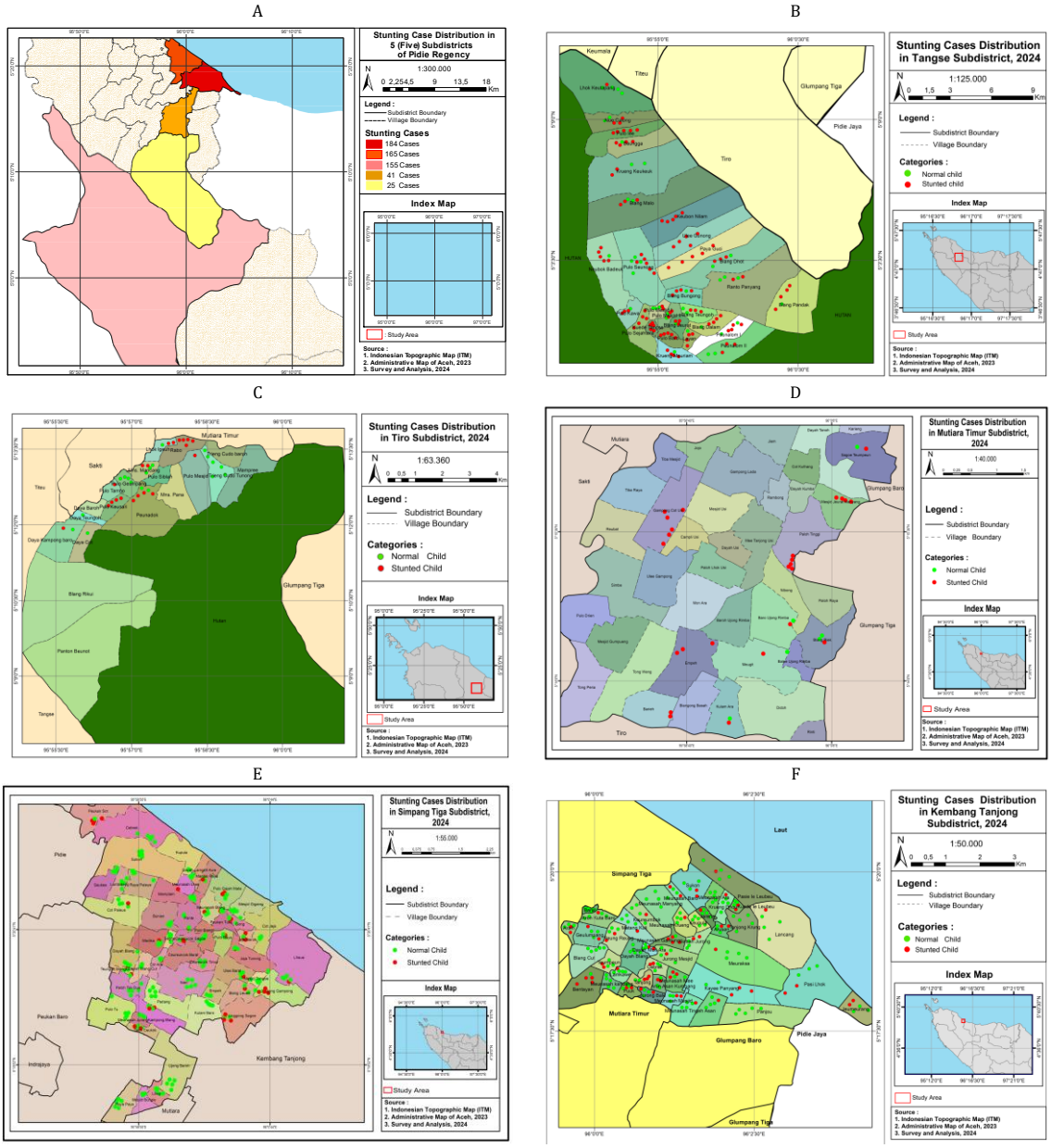

Fig. 7: (A) Distribution of stunting cases in 5 sub-districts in Pidie district; (B) Distribution of stunting cases in Tangse Sub-district; (C) Distribution of stunting cases in Tiro Sub-district; (D) Distribution of stunting cases in Mutiara Timur Sub-district; (E) Distribution of stunting cases in Simpang Tiga Sub-district; (F) Distribution of stunting cases in Kembang Tanjong Sub-district

The entrenched cultural norms in Pidie District heavily shape parental behaviors, which contribute to the ongoing issue of child stunting. Standard practices, like early marriages and formula feeding instead of exclusive breastfeeding, persist despite modernization efforts (Hamdani et al., 2024). These behaviors highlight the urgent need for tailored educational initiatives that provide information and actively involve parents in adopting optimal child-rearing practices. Interestingly, higher education levels among parents do not guarantee better childcare behaviors, emphasizing the essential role of ongoing support and supervision from healthcare professionals in promoting child health.

In line with this finding, we explored the relationship between religion and culture in Keureumbok village, Pidie District, finding that cultural traditions often substantially impact community behavior more than religious teachings. This cultural dominance can cause tensions between

traditional practices and religious directives, especially when individuals educated in urban areas or Islamic boarding schools return to their communities and face deeply rooted local customs (Lansford, 2022). These findings suggest that cultural norms largely influence parenting practices, highlighting the need for culturally sensitive interventions to combat stunting effectively.

The transition towards a more consumptive lifestyle, influenced by exposure to foreign cultures, has further complicated nutritional issues in rural areas. A growing focus on material goods, such as smartphones and brand-name products, among youth often overshadows fundamental dietary needs (Shah and Phadke, 2023). This trend signifies a broader societal shift where the pursuit of social status is prioritized over health imperatives, further entrenching unhealthy consumption behaviors (Dao et al., 2020).

Family lifestyle decisions that neglect child development are major contributors to stunting. A link between socioeconomic status and child health outcomes was identified, indicating that a higher family income generally leads to better health results (Vaivada et al., 2020). However, in Pidie, even children from wealthy families face substantial stunting rates due to poor lifestyle choices despite having ample resources. A particularly alarming trend is the preference for formula feeding over exclusive breastfeeding among adolescent mothers, often stemming from inadequate knowledge about child development (Sufri et al., 2023; Hamdani et al., 2024). These findings align with studies emphasizing the critical roles of midwives, community health workers, familial support, and maternal motivation in behaviors that prevent stunting. The active engagement of community health workers is pivotal in improving public health outcomes, as systematic tracking of maternal health, child growth, and preventive health measures during essential early life stages can significantly mitigate stunting.

Recent studies reinforce these conclusions. For instance, spatial analysis in East Nusa Tenggara Province revealed that environmental and economic factors, such as poor sanitation and limited clean drinking water, correlate strongly with high stunting rates. Similarly, negative binomial spatial regression was employed to identify predictors of stunting in West Java, finding that low rates of exclusive breastfeeding and inadequate food processing practices contribute to stunting occurrences (Djuraidah et al., 2023). These investigations highlight the complex nature of stunting and the necessity for broad, context-specific strategies that address cultural practices and socioeconomic factors.

Implementing this study may have several limitations; firstly, focusing on five sub-districts in Pidie limits generalizability due to their unique socioeconomic and cultural contexts. Future research should encompass diverse settings to enhance external validity. Second, self-reported data may introduce response bias, affecting reported socioeconomic status, parenting practices, and health behaviors; employing objective measures, such as direct observations or health records, would improve reliability.

5. Conclusion

Research findings across Pidie District's five sub-districts—Tangse, Tiro, Simpang Tiga, Kembang Tanjong, and Mutiara Timur—show that Tangse has a 79.1% prediction rate for toddler stunting due to individual and community factors. Tiro's stunting rate is predicted at 60%, influenced by individual and societal conditions. Mutiara Timur shows a minimal effect at 18.68%. Simpang Tiga has a strong prediction of 84%, driven by individual and household factors, while Kembang Tanjong is 83.8%. GIS analysis indicates the highest stunting prevalence in Mutiara Timur at 83.7%, followed by Tangse at 73.5%, Kembang Tanjong at 57.3%, Tiro at 54.3%, and the lowest in Simpang Tiga.

To successfully reduce stunting in Pidie District, policymakers need to implement tailored interventions that consider sub-district characteristics, enhance Posyandu and outreach services, and utilize GIS-informed planning to tackle disparities. Merging health programs with socioeconomic development, encouraging evidence-based decision-making using SEM-PLS and GIS tools, and promoting collaboration across sectors are crucial. These approaches facilitate focused, data-driven efforts to improve child health and equitably lower stunting rates throughout the region.

List of abbreviations

BL	Body length
BMI	Body mass index
BPS	Statistics Indonesia (Badan Pusat Statistik)
BW	Body weight
CAR	Conditional autoregressive
CHLB	Clean and healthy living behavior
CSDH	Conceptual social determinants of health
e-PPGBM	Community-based nutrition recording and reporting system
GERMAS	Healthy living community movement
GIS	Geographic information systems
HCMC	Ho Chi Minh City
MGA	Multi-group analysis
PHBS	Prilaku hidup bersih dan sehat
Puskesmas	Community health centers
RPJM	National medium-term development plan
R^2	Coefficient of determination
SD	Standard deviation
SEM-PLS	Structural equation modeling–partial least squares

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Compliance with ethical standards

Ethical considerations

This study received approval from the Research Ethics Committee of Syiah Kuala University, Darussalam, Banda Aceh, Indonesia, under number 109/EA/FK/2023. Moreover, before data collection, enumerators underwent training in stunting assessment methodologies conducted by faculty members from Syiah Kuala University to guarantee the accuracy and reliability of data collection. Data collection was organized based on the availability of respondents, aligning with prior agreements established between participants and enumerators. This methodology ensured the data's validity and upheld ethical standards concerning respondent engagement.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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