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Dynamic Model of Stunting Incidents and Policies in Padang City

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ABSTRACT

Stunting remains a significant public health challenge with complex, interconnected causative factors. Traditional static approaches fail to capture the dynamic relationships between environmental, health, and socioeconomic determinants. Dynamic modeling is essential for understanding these multifaceted interactions and developing effective prevention policies. Despite declining trends, Padang City's high prevalance of stunting necessitates urgent, targeted interventions to achieve national targets. This study aims to develop a dynamic model analyzing stunting factors in Padang City and formulate effective prevention policies. A quantitative descriptive method with a dynamic systems approach was employed. Primary data were obtained through stakeholder questionnaires, while secondary data were obtained from the Padang City Health Office and Statistical Reports (2018-2023). Analysis utilized PowerSim Studio 10 for dynamic systems modeling and Interpretative Structural Modeling (ISM) for policy strategy development. Seven main factors influencing stunting were identified: low birth weight, maternal health, immunization, diarrhea, living in slum areas, access to clean water access, and household sanitation. Simulation modeling demonstrated that improving environmental conditions, increasing immunization coverage, and administering iron tablets could reduce stunting rates by 50% over 25 years. ISM analysis revealed environmental factors (sanitation, waste management, and access clean water) as key elements with the highest driving force. Consistent immunization coverage could reduce stunting prevalence from 24.2% to 12% within the projection period, while improved sanitation programs may lower prevalence by 15%. The research provides an integrated approach prioritizing basic infrastructure improvement, environmental sanitation enhancement, cross-sector coordination, and community capacity building. This dynamic modeling framework offers valuable insights for comprehensive stunting prevention strategies. However, limitations include a modeling-only scope requiring field validation for implementation effectiveness.

INTRODUCTION

Indonesia's "Golden Indonesia 2045" vision prioritizes public health and nutrition, particularly addressing stunting as key to developing a superior generation.[1] Stunting, defined as impaired growth in children under five due to chronic malnutrition,[2] remains a critical challenge with aprevalence at 21.6% in 2022,[3] which rank among the world's top 10 countries with highest stunting burden.[4]

This challenge aligns with the 2030 Sustainable Development Goals targeting malnutrition elimination,[5,6] as malnutrition contributes to approximately 45% of under-five deaths globally.[7]Despite global reductions from 155 million (2016) to 148 million (2021) stunted children worldwide, the burden remains substantial.[8]

Research identifies biological factors as primary stunting determinants, with children aged 12-23 months at higher risk and low birth weight increasing risk 2-3-fold.[9,10] Maternal health and nutrition during pregnancy also contribute significantly to stunting outcomes.[11]

Socioeconomic factors, particularly low family income and maternal education, are strongly associated with higher stunting rates.[12,13,14] Maternal education plays a crucial role in increasing knowledge about nutrition, health, and feeding practices, directly impacting child growth.[14]

Environmental and lifestyle factors significantly influence stunting prevalence. Poor sanitation, exposure to cigarette smoke, limited access to clean air, and poor drinking water quality contribute to infectious diseases leading to stunting.[11,15,16] Research demonstrates significant relationships between water quality and stunting in Indonesia.[16]

In West Sumatra, parenting patterns emerged as the primary factor associated with stunting, supported by four research articles. This is followed by low birth weight, exclusive breastfeeding practices, complementary feeding, and environmental sanitation, each supported by three articles.[17]

The Indonesian government launched comprehensive interventions including the National Movement for Nutrition Improvement,[18] and the Presidential Regulation No. 72/2021 on Stunting Reduction Acceleration.[19] This regulation encompasses national strategy, implementation, coordination, monitoring and evaluation, and funding mechanisms.

West Sumatra achieved progress from 28.5% (2019) to 25.2% (2022) stunting prevalence, targeting 12.5% by 2025 and 10.6% by 2026 according to the 2021-2026 Regional Development Plan. However, these rates still exceed the WHO threshold of 20%.

Padang City presents a critical anomaly: stunting prevalence increased from 19.5% (2022) to 24.2% (2023), representing a 4.70% increase.[18,19] This trend is particularly concerning given Padang's status as the provincial capital and economic center, suggesting that conventional interventions are inadequate.

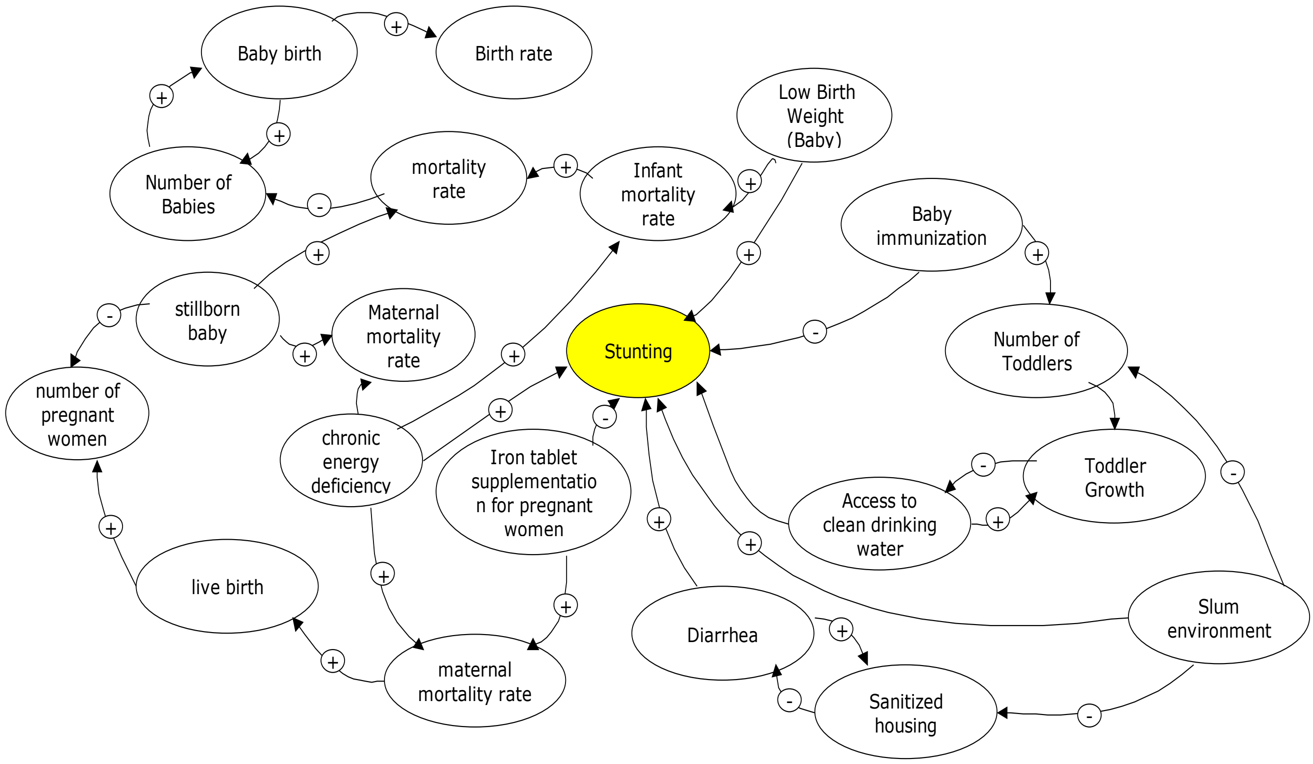
Previous stunting research predominantly employed statistical analysis examining direct factor relationships a fundamentally limited approach for understanding stunting's systemic complexity. Dynamic systems modeling offers superior analytical capacity by capturing feedback loops, modeling non-linear relationships, simulating policy scenarios over time, and identifying high-leverage intervention points.[20,21] This study aims to build the first dynamic model of stunting prevention in Padang City, representing a critical methodological advancement for addressing this complex public health challenge and supporting the achievement of 2030 SDGs and "Golden Indonesia 2045" vision.

MATERIAL AND METHOD

This study uses a quantitative descriptive method with a dynamic systems approach to analyze the factors influencing stunting in Padang City. This approach was chosen to understand the complex interactions among factors and provide effective stunting prevention policy recommendations. The study population was all stunting data and related factors in Padang City for the 2018-2023 period. The types of data used were primary and secondary data. Secondary data were obtained from reports from the Padang City Health Office, the "Padang City in Figures" document for the 2018-2023 period, and documents on stunting prevention programs and regulations. Primary data were obtained through questionnaires distributed to three key informants: representatives from the Padang City Health Office, a public policy expert, and a local community leader. The questionnaire was validated by validators who are experts in their fields to ensure the quality of the research instrument.

The collected data were analyzed quantitatively using three main approaches. Descriptive analysis was conducted to describe the stunting case data in Padang City, which is presented in tabular form. System dynamics modeling used PowerSim Studio 10 with a system methodology limited to the modeling stage, including: (1) black box input-output diagrams, (2) development of causal loop diagrams, and (3) technical analysis through stock flow diagrams. The modeling stage begins with understanding and reviewing the system, then developing a causal loop diagram that includes all causal interactions related to the stunting problem. Based on the causal loop diagram, system level and rate diagrams are then constructed that illustrate the various interactions between entities in the system using Powersim Studio 10 software.[21] This study limits the scope to the modeling stage (marked by the red dotted line) and does not proceed to the implementation stage. This limitation was made because the focus of the research is the development of a system dynamics model as a policy analysis tool, not the direct implementation of a stunting prevention program. The resulting model aims to help stakeholders understand the dynamics of factors causing stunting and simulate intervention scenarios before implementation in the field.

Once the model boundaries are defined, a feedback loop interaction structure diagram can be formed. The feedback structure is the building block of the model expressed through a closed loop.[22,23] In this study, the formulation of the stunting policy in Padang City is formulated in the form of a Cause-and-Effect Loop Diagram, as seen in Figure 1.



Source: Variable Processing Results with Powersim Studio, 2024

Figure 1. Circle Diagram of Cause and Effect of Stunting Incidents in Padang City

Based on the causal loop, a system level and rate diagram are constructed. This diagram will illustrate the various interactions/relationships between entities within the system. The development of the level and rate diagram was carried out using Powersim software. A system model was developed, formulated as a representation or abstraction of all interactions occurring within the system under study.[22] Once the model was obtained, a questionnaire was distributed to three key informants. The questionnaire results were then analyzed using the Interpretative Structural Modeling (ISM) method for strategic policy planning. The ISM method is implemented through seven systematic stages: (1) breaking down the main elements into more specific sub-elements, (2) determining the contextual relationships between sub-elements based on the opinions of informants, (3) compiling the SSIM (Structural Self-Interaction Matrix) matrix using the symbols V, A, X, and O, (4) creating a reachability matrix by converting the SSIM symbols into binary values, (5) calculating transitivity to ensure logical consistency, (6) compiling the hierarchical structure levels of sub-elements, and (7) creating a Driver Power-Dependence matrix to identify the driving and dependent elements in the stunting prevention system.[21] Data processing is carried out with the help of Microsoft Excel for ISM and PowerSim Studio 10 for dynamic system simulation. Based on the results of the ISM analysis, appropriate policy recommendations will be generated.

This study received approval from the local ethics committee and permission from the Padang City Health Office. All primary data collection through questionnaires obtained informed consent from participants, ensuring confidentiality and voluntary participation. The dynamic system model was validated through historical data comparison (2018–2023) and expert validation with public health and policy experts (face validity). The model outcomes were compared against actual stunting trends to ensure behavioral validity.

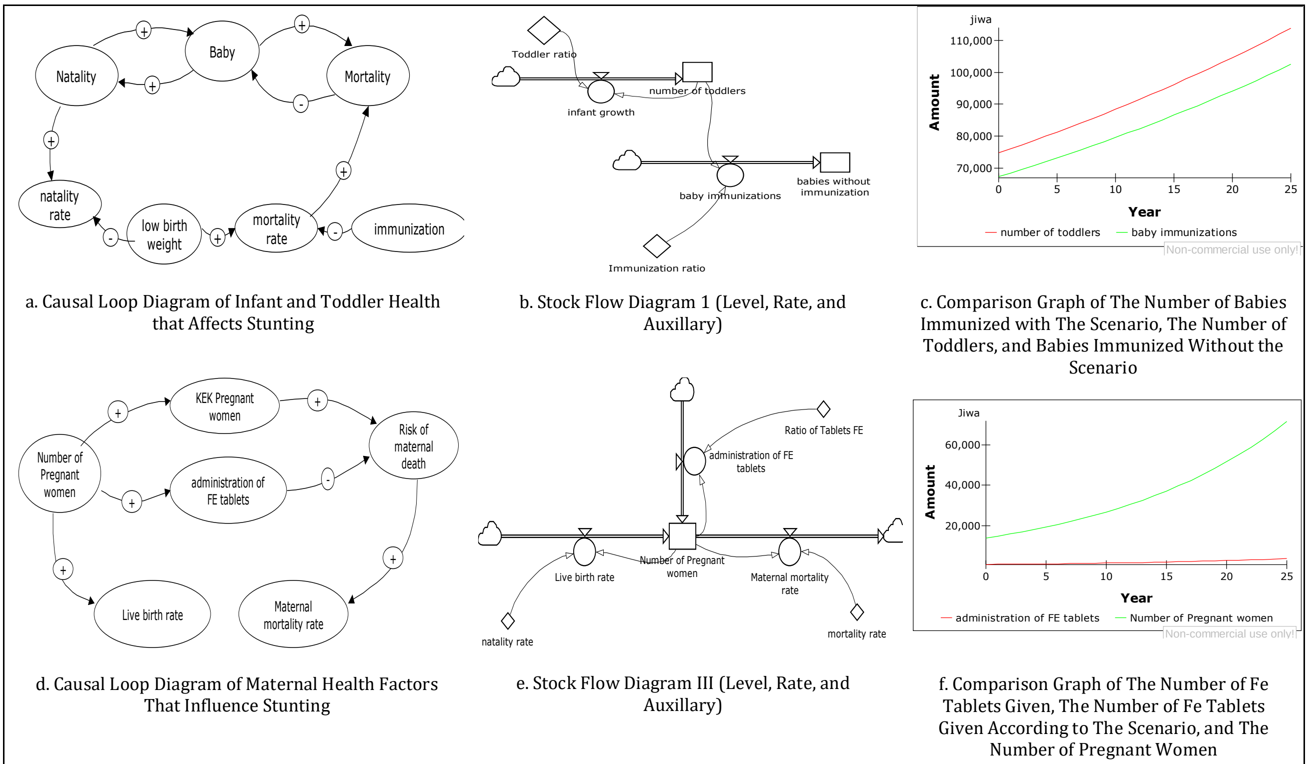
RESULTS

Based on the data on stunting factors that have been analyzed; to find out how the stunting prediction model was developed with the stages in creating a dynamic system model, it can be seen in Figure 2.

Based on the scenario results in Figure 2, the simulation shows that a consistent immunization program can increase infant immunization coverage for the next 25 years. This increase in infant immunization coverage will have a positive impact on infant health, thereby preventing stunting. Meanwhile, the graph of the results of running Fe tablet administration displays the presentation between the actual Fe tablet administration, the scenario, and the number of pregnant women in Padang City, which shows that there are 692 people receiving Fe tablets actually, 1,480 people in the scenario, and 18,275 people in total pregnant women in Padang City in 2018-2023. The data reveals a fairly large distribution between the number of pregnant women who continue to increase and the provision of Fe tablets, both in actual conditions and scenarios, thus indicating the need to increase the Fe tablet administration program to balance the growth in the number of pregnant women in Padang City.

The Stock Flow Dynamic (SFD) Model of stunting incidents in Padang City based on dynamic systems can be seen in Figure 3. Figure 3 depicts a complex system model for understanding the factors causing stunting. The flow begins with infant growth data, then is influenced by various environmental risk factors (sanitation, diarrhea, clean water access, slum areas) and protective factors (immunization, iron supplementation). Scenario simulations show that improving environmental conditions has a significant impact on reducing stunting rates. The following graph shows the comparison of the number of stunted toddlers with the interventions.

The simulation results in Figure 4 show that although the total number of toddlers is projected to increase exponentially, the implementation of an integrated intervention model that optimizes environmental factors, sanitation, immunization, iron tablet administration, diarrhea control, and access to clean drinking water has significant potential to control the growth rate of stunting cases. The gap between actual conditions and the results of the modeling simulation proves that a planned and comprehensive intervention strategy can be an effective solution in reducing stunting rates in toddlers, thus emphasizing the urgency of implementing an integrated approach in stunting prevention programs.



a. Causal Loop Diagram of Infant and Toddler Health that Affects Stunting

b. Stock Flow Diagram 1 (Level, Rate, and Auxillary)

c. Comparison Graph of The Number of Babies Immunized with The Scenario, The Number of Toddlers, and Babies Immunized Without the Scenario

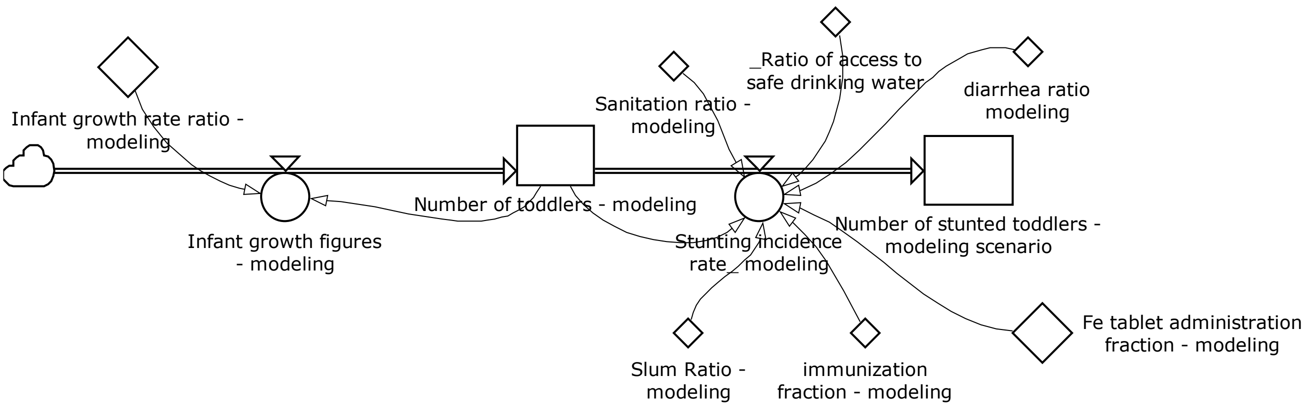
d. Causal Loop Diagram of Maternal Health Factors That Influence Stunting

e. Stock Flow Diagram III (Level, Rate, and Auxillary)

f. Comparison Graph of The Number of Fe Tablets Given, The Number of Fe Tablets Given According to The Scenario, and The Number of Pregnant Women

Source: Variable Processing Results with Powersim Studio, 2024

Figure 2. Causal Loop Diagram, Flow Diagram, and Dynamic Model of Infant, Toddler and Maternal Health Scenarios Regarding Stunting Incidents in Padang City



Source: Variable Processing Results with Powersim Studio, 2024

Figure 3. Dynamic System-Based Stunting Incident Model in Padang City

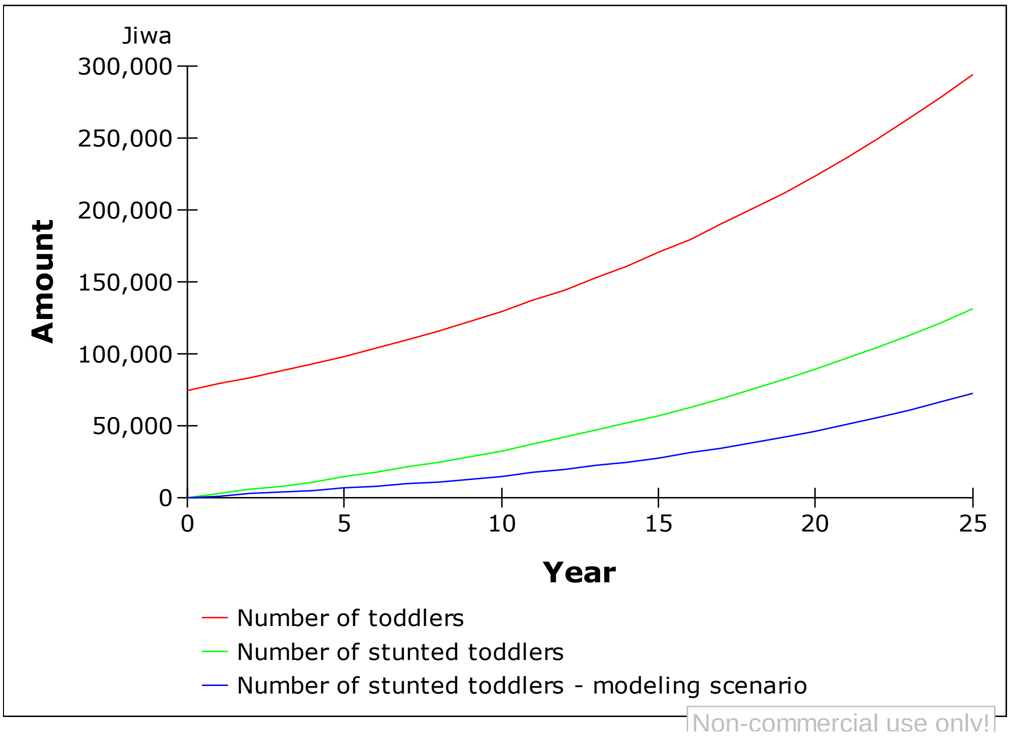
Based on the Table 1, simulation results indicate that maintaining immunization coverage above 90% could reduce stunting prevalence by 50% over 25 years. Coverage of Fe tablets, however, showed a gap of 26% between pregnant women in need (18,275) and those who received supplementation (13,518). This quantification highlights the urgency of strengthening supplementation programs.

Policy Analysis for Handling Stunting in Padang City Using Interpretative Structural Modeling (ISM)

The questionnaire analysis successfully identified nine key elements that form the foundation of stunting management in Padang City, including environmental sanitation and basic infrastructure (E1), waste and sewage managegement (E2), access to clean water (E3), integrated immunization programs (E4), iron tablet supplementation (E5), public health education (E6), program coordination and governance (E7), family and community capacity building (E8), and health integration programs (E9) (Figure 5). The identification of these elements was obtained through input from three strategic respondents consisting of public policy experts, health service representatives, and community leaders, thus providing a comprehensive perspective from various perspectives of stakeholders directly involved in stunting prevention and management efforts in the region.

The image analysis in the RM table identified three main priority programs in handling stunting, namely sanitation improvement (E1), waste and waste management (E2), and clean water provision (E3) which have the highest influence, followed by the integrated immunization program (E4) in second place. The program coordination and governance program (E7) is the most dependent on other programs, while the public health education program (E6), the provision of Fe tablets (E5), and the health integration program (E9) have a lower level of influence, indicating the importance of focusing on basic infrastructure as the main foundation for stunting prevention. Structural analysis using the Driver Power-Dependence (DPD) Matrix produces two main hierarchical levels that can be seen in the Figure 6.

The Driver Power-Dependence (DPD) Matrix analysis reveals a three-tier hierarchical structure in the stunting management system, where basic infrastructure in the form of environmental sanitation (E1), waste and sewage management (E2), and access to clean water (E3) are the main driving foundations at Level I, followed by integrated immunization programs (E4) and program governance coordination (E7) as the link at Level II, and Fe tablet supplementation programs (E5), health education (E6), capacity building (E8), and health program communication (E9) at Level III, which are highly dependent on the elements below them. This structure indicates that successful stunting prevention requires a phased and integrated approach with a top priority on strengthening basic infrastructure as a fundamental prerequisite for the effectiveness of health intervention programs at higher levels.



Source: Variable Processing Results with Powersim Studio, 2024

Figure 4. Graph of Simulation Results Comparing The Number of Toddlers, The Number of Stunted Toddlers, and The Number of Scenarios Stunted Toddlers in Padang City

Table 1. Summary of Simulation Results

Scenario	Stunting Prevalence (Projection)	Reduction Compared to Baseline
Immunization Coverage ≥90%	12%	↓ 50%
Fe Tablet Coverage ≥90%	15%	↓ 35%
WASH Improvement (sanitation + clean water)	20%	↓ 15%
Integrated Approach (all interventions)	10%	↓ 60%

Source: Primary Data, 2024

No	Element	Column	Code	E1	E2	E3	E4	E5	E6	E7	E8	E9
				J								
1	Improved environmental sanitation and basic infrastructure	I	E1		X	X	V	V	V	V	V	V
2	Waste management and waste		E2			X	V	V	V	V	V	V
3	Provision of access to clean water		E3				V	V	V	V	V	V
4	Integrated immunization program		E4					X	V	V	V	V
5	Public health education		E5						X	A	V	A
6	Fe tablet supplementation program.		E6							V	V	A
7	Coordination and Program Governance		E7								V	V
8	Strengthening Family and Community Capacity		E8									A
9	Integration of Health Programs		E9									

a. Structural Self-Interaction Matrix (SSIM) Table Compilation

Description:
1.V: If Column I is more important than Column
2.A: If Column J is more important than Column
3.I; X: When I and J are equally important;
4. O: When Columns I and J are not related

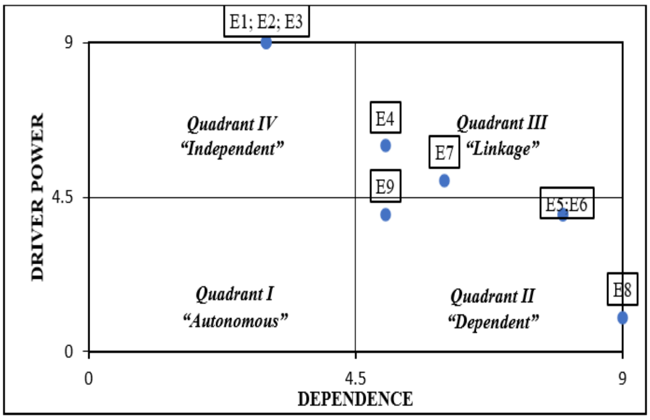
Code	E1	E2	E3	E4	E5	E6	E7	E8	E9	Driver Power	Ranking
E1	1	1	1	1	1	1	1	1	1	9	1
E2	1	1	1	1	1	1	1	1	1	9	1
E3	1	1	1	1	1	1	1	1	1	9	1
E4	0	0	0	1	1	1	1	1	1	6	2
E5	0	0	0	0	1	1	0	1	0	4	4
E6	0	0	0	0	1	1	1	1	0	4	4
E7	0	0	0	0	1	1	1	1	1	5	3
E8	0	0	0	0	0	0	0	1	0	1	5
E9	0	0	0	0	1	1	0	1	1	4	4
Dependence	3	3	3	5	8	8	6	9	5		
Level	5	5	5	4	2	2	3	1	4		

b. Preparation of Reachability Matrix (RM)

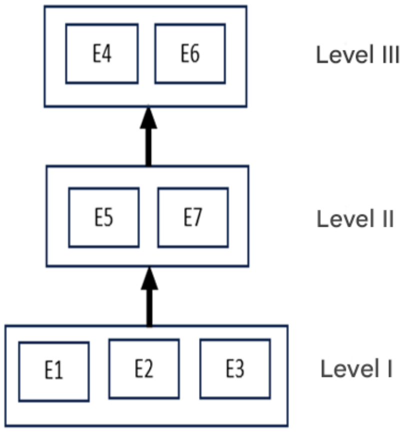
Description:
1.If the relationship V (i is more important than j), then: Matrix [i, j] = 1, and [j, i] = 0.
2.If the relationship A (j is more important than i), then: Matrix [i, j] = 0, and [j, i] = 1.
3.If the relationship X (i and j are equally important), then: Matrix [i, j] = 1, and [j, i] =1.
4.If the relationship is O (no relationship), then: Matrix [i, j] = 0, and [j, i] = 0.

Source: Primary Data, 2024

Figure 5. a. Analysis Using the Structural Self-Interaction Matrix (SSIM) and b. Compilation Reachability Matrix (RM)



a. The Relationship between Driver Power and Dependence on Key Elements of Stunting Management in Padang City



b. Hierarchical structure of elements in stunting prevention in Padang City

Source: Primary Data, 2024

Figure 6. Driver Power Dependence (DPD) Matrix and Key Element Hierarchy Structure

DISCUSSION

The positive trend in stunting prevention in Padang City is evident in the decline in Low Birth Weight (LBW) cases from 270-296 to 185 in 2023. This finding aligns with research by Murti et al. (2020), which identified that low birth weight babies have a 5.6 times greater risk of stunting. This decline demonstrates improvements in the quality of antenatal care services and maternal nutrition education, which have positively impacted stunting prevention efforts in the region.[24]

A serious challenge arises from the decline in iron tablet provision from 16,900 people (2018) to 13,518 people (2023). Tiwery et al., (2023) explained that iron deficiency during pregnancy not only increases the risk of anemia but also weakens the strong incidence of stunting (OR = 3.78).[25] This decline in coverage is likely the impact of the COVID-19 pandemic which hampers access to health services, thus requiring a special strategy to increase iron supplementation coverage again. Access to clean drinking water in Padang City shows encouraging progress with an achievement of 97.6% in 2023. Cronin et al., (2016) found that poor access to clean water increases the risk of stunting by 2.4 times, making this achievement an important foundation for stunting prevention. However, challenges remain with proper sanitation, which has only reached 77.8%, which has the potential to reduce the effectiveness of achieving clean water access. Suboptimal sanitation conditions are reflected in the increase in diarrhea cases from 4.1% (2021) to 6.9% (2023).[26] A study by Shafira et al., (2024) in Medan City demonstrated that poor sanitation practices significantly influence stunting incidence, with poor handwashing (OR = 4.125), inadequate toilets (OR = 7.211), and poor waste management (OR = 2.681).[27] Nasrul et al., (2020) confirmed that recurrent diarrhea can increase the risk of stunting by 3.7 times.[28] Dynamic modeling of stunting incidence using Powersim Studio 10 reveals complex interactions between various determinants of stunting. Kusumawati et al., (2021) found that a dynamic systems approach can identify feedback loops in stunting, particularly the role of immunization as an effective preventive intervention.[29] Simulation models for a 25-year projection indicate that consistently increasing immunization coverage can reduce the risk of stunting, in line with research by Prendergast et al. (2019) on the contribution of complete immunization to optimizing children's linear growth.[30]

A significant gap between the number of pregnant women and the coverage of iron tablet provision was identified through dynamic modeling. Rahman et al., (2018) found that iron supplementation during pregnancy can reduce the risk of stunting by 34%.[31] The identified gap in coverage of iron tablets indicates the need for a strengthened iron supplementation program in accordance with WHO recommendations to achieve a minimum coverage of 90% among pregnant women.

A 25-year simulation showed that although the number of toddlers is projected to increase exponentially, integrated interventions on determinants can suppress the growth rate of stunting cases. Christian et al., (2015) demonstrated that simultaneous improvements in sanitation, maternal nutrition, and immunization coverage can reduce stunting prevalence by up to 40% within 5 years.[32] These findings reinforce the argument of Harding et al., (2019) that a multisectoral approach that integrates environmental improvements, maternal health, and child health has proven most effective.[33]

Interpretative Structural Modeling (ISM) analysis places environmental factors as an independent element with the highest driving force. Torlesse et al., (2016) revealed that poor sanitation increases the risk of stunting by 1.3 times in Indonesia.[34] Prendergast & Humphrey (2014) found that children living in environments with poor sanitation have a 2.1 times greater risk of stunting. This is explained through the mechanism of Environmental Enteric Dysfunction (EED), where exposure to environmental pathogens causes chronic intestinal inflammation and interferes with nutrient absorption.[35] The significance of environmental factors is reinforced by Aguayo & Menon (2016) who found that the effectiveness of specific nutrition programs decreases drastically in areas with poor sanitation.[36] Cumming & Cairncross (2016) showed that interventions to improve sanitation and access to clean water can reduce the risk of stunting by up to 15%.[37] A WHO meta-analysis (2018) of 42 countries confirmed a strong correlation between access to clean water and proper sanitation and a decrease in stunting prevalence.

The ISM findings support the World Bank's (2022) argument on the cost-effectiveness of WASH investments in stunting prevention, which estimated that every $1 invested in sanitation improvements results in $4.3 in health care savings and long-term productivity gains. Practical implications for Padang City include mapping detailed sanitation infrastructure needs as a basis for planning interventions, synchronizing WASH programs with specific nutrition interventions, and strengthening institutional capacity at the village level for sanitation infrastructure maintenance.[38]

The gap in Fe tablet coverage remains a serious challenge as low supplementation rates contribute to persistent anemia and higher stunting risk, consistent with global evidence. The study is limited by the small number of key informants (n = 3), reliance on secondary data from 2018–2023, and lack of field-based validation. Future studies should involve larger sample sizes and pilot testing of the model in real-world interventions. Increasing iron supplementation coverage must be integrated with WASH and immunization programs. A multisectoral strategy that aligns maternal health, child nutrition, and infrastructure development will ensure sustainable stunting reduction.

CONCLUSION AND RECOMMENDATION

The dynamic system modeling revealed that sanitation, clean water access, immunization, and iron supplementation are the most influential factors in preventing stunting in Padang City. Model projections indicate that improvements in these key areas could reduce the prevalence of stunting by approximately half over the next 25 years. Therefore, it is recommended to increase the coverage of iron (Fe) tablet supplementation to at least 90% among pregnant women, expand water, sanitation, and hygiene (WASH) infrastructure with a primary focus on sanitation and clean water, and strengthen immunization programs to maintain coverage above 90%. In addition, enhancing multisectoral coordination across health, education, and infrastructure sectors is essential to ensure the effectiveness and sustainability of stunting prevention efforts.

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AUTHOR CONTRIBUTIONS

Conceived and designed the research by EY and NA; EY collected the data; NA analyzed the data and wrote the manuscript; Y, FADN, NS, IU, and H reviewed and edited the manuscript. All authors read and approved the final manuscript. EY = Elsa Yuniarti; NA = Nabila Azzahra; Y = Yulhendri; FADN = Fitra Arya Dwi Nugraha; NS = Nurhasan Syah; IU = Iswandi Umar; H = Heldi.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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