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Analysis of the Effect of Local Food-Based Nutritional Intervention on Stunting Dynamics in Central Kalimantan: Mathematical Modeling and Simulation Approach

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Abstract. Central Kalimantan is the 11th province with the highest stunting prevalence in Indonesia which 26,9% in 2022. The government is carried out various spesific and sensitive interventions to accelerate the reduction in stunting prevalence which is targeted to decrease to 15,38% in 2024. This study aims to analyse the dynamics of stunting in children under five in Central Kalimantan with the influence of local food-based nutritional interventions, snakehead fish and moringa leaves, through mathematical modelling and simulation**.** This ordinary differential equation system (ODE) model consisting of four variables: the proportion of children under-five at risk of stunting $R(t)$, the proportion of stunted children under five $S(t)$, the proportion of children under five who receive nutritional interventions $I(t)$, and the proportion of children under five at risk of stunting who successfully become normal after receiving nutritional intervention $N(t)$. This system only has a stunting equilibrium point which locally asymptotically stable. Simulation of model was conducted with three scenarios to compare the effectiveness of nutritional intervention, without nutritional intervention, with local food-based nutritional intervention except snakehead fish and oringa leaves, and with local food-based nutritional intervention using snakehead fish and moringa leaves. The results of the model simulation show local food-based nutritional intervention very helpful in reducing the prevalence of stunting, especially in Central Kalimantan, and snakehead fish and moringa leaves has the potential to improve their efficacy, thereby accelerating the reduction in the stunting prevalence.

Keywords: Differential equation system, local food, mathematical modelling, stunting.

1 Introduction

Stunting is a term for a condition caused by prolonged chronic malnutrition and frequent infections that inhibit the growth and development of children under five [1], [2]. The government is still concentrating on finding solutions to the stunting issue, even in Central Kalimantan. According to the Indonesian Nutritional Status Survey (SSGI) data, Central Kalimantan has the 11th-highest prevalence of stunting (26.9%) among 38 provinces in Indonesia as of 2022 [3], then in 2023, this percentage decrease to 23.5%. This number is still more than the 20% WHO criterion, though.

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Stunting negatively impacts a person's ability to develop cognitively, physically, and productively in the future [4], [5]. Stunting has been reported to increase morbidity and mortality in children under five [6]. Thus, Indonesia's high rate of stunting will make it difficult to produce the golden generation of 2045.

The Central Kalimantan Provincial Government through the Stunting Reduction Acceleration Team (TPPS) consisting of various agencies and regional apparatus organizations (OPD) has carried out various spesific and sensitive interventions to accelerate the reduction in stunting prevalence which is targeted to decrease to 15,38% in 2024 [7]. In Central Kalimantan, efforts to reduce stunting are being carried out through various nutritional treatments, such as local food diversification. The region has a variety of local foods that are rich in nutrients important for children's growth and development. Examples include snakehead fish, and moringa leaves [8], [9]. Although so far improving the nutritional status of children under five has been done by providing food with local ingredients such as eggs, chicken, and fish, providing snakehead fish and moringa leaves or their processed products has greater potential in influencing the improvement of the nutritional status of children under five. This is because their nutritional content is more complete and is very much needed for optimal children under five growth. In other words, the use of these local food ingredients in nutritional interventions is useful for preventing stunting in children under five [10], [11].

Snakehead fish are noted for having a full and high-quality animal protein content of about 25.2 grammes per 100 grammes of material, a relatively high albumin level of about 6.2 grammes, and an iron content of 9 mg [12]. Furthermore, the body can easily assimilate snakehead fish. When it comes to meals like eggs, chicken, and beef, snakehead fish has a greater protein level. As a result, giving children under-five snakehead fish is a great way to improve their nutritional status [8].

Another local food ingredient is Moringa leaves (Moringa Oleifera). Moringa leaves contain calcium which is useful for increasing children's height [13]. Moreover, potassium, phosphorus, zinc, and iron are found in moringa leaves and can be added to a variety of processed foods to make up for dietary deficits [14] and decrease stunting prevalence [15]. A 100 grammes of dried Moringa leaves contains 7.5% water, 205 grammes of calories, 38.2 grammes of carbs, 27.1 grammes of protein, 2.3 grammes of fat, 19.2 grammes of fibre, 2003 mg of calcium, 368 mg of magnesium, 204 mg of phosphorus, 0.6 mg of copper, 28.2 mg of iron, 870 mg of sulphur, and 1324 mg of potassium [9].

The stunting dynamics can be described by a mathematical model. Mathematical modelling of SEIR epidemiology by analysing the influence of sanitation factors has been previously carried out in [16]. The results of their study suggest that the faster sanitation solutions improve, the fewer incidences of stunting will occur. Stunting rates were shown to be greatly lowered by mental health care, education, and social support, according to the research utilising the SEIR mathematical model [17]. Then a mathematical model of BSIR compartments with actions is suggested to lower the prevalence of stunting [2]. Without doing simulations, this model depicts the prevalence of stunting transmission.

This study develops a new mathematical model for stunting dynamics that differs from existing mathematical model for stunting, primarily adapted from epidemiological models (SIR/BSIR). This model offers a more accurate and context-specific approach to analyzing stunting dynamics by incorporating the non-infectious nature of stunting and emphasizing the role of local food-based nutritional interventions. Using this model and simulations, we analyse the impact of local food-based nutritional interventions on stunting dynamics in Central Kalimantan, spesifically how they affect the prevalence of stunting of children under five. This is a compartmental mathematical model in the form of an ordinary differential equation system (ODE System). Through this study, we want to contribute by providing recommendations for more effective nutritional interventions in efforts to control stunting in Central Kalimantan. We will integrate the estimated effectiveness of local foods, snakehead fish and morinaga, in improving the nutritional status of children under five in several other areas into the mathematical model that we have prepared, then we will compare it with the effectiveness of nutritional interventions in Central Kalimantan according to the data in the model simulation so that we can see how quickly local foods affect the reduction in stunting prevalence in this area. Model simulations are carried out using Python programming.

2 Mathematical Modelling

2.1 Model Formulation

This article will discuss a mathematical model to analyse the impact of local food-based nutritional interventions on stunting dynamics in Central Kalimantan. This model consists of four variables, $R(t)$, $S(t)$, $I(t)$, and $N(t)$, each stating the proportion of children under five at risk of stunting, the proportion of stunted children under five, the proportion of children under five receiving nutritional interventions, and the proportion of children under five at risk of stunting who successfully become normal after receiving nutritional intervention. Some of the assumptions used in this modelling are:

1. Although [6] has been reported that stunted children under-five can recover to normal due to various supporting factors, due to the limited data in our area, we assume that children under-five who have experienced stunting cannot recover (return to normal); intervention for stunted children under-five can only prevent the stunting condition from getting worse.
2. The effectiveness of local food-based nutritional interventions is higher than the effectiveness of general nutritional interventions.
3. The infant mortality rate is assumed to be the same for each compartment.
4. Children under five who have returned to normal may be at risk of stunting again because they do not get enough nutrition.
5. Both stunted children under five and children under five at risk of stunting have equal access to nutritional interventions.
6. Children under five who received nutritional intervention were evenly distributed in the age range 0-59 months.
7. Children under five who have returned to normal have better health and nutritional conditions than children under five at risk of stunting.

The compartment diagram of this stunting model is illustrated in Figure 1.

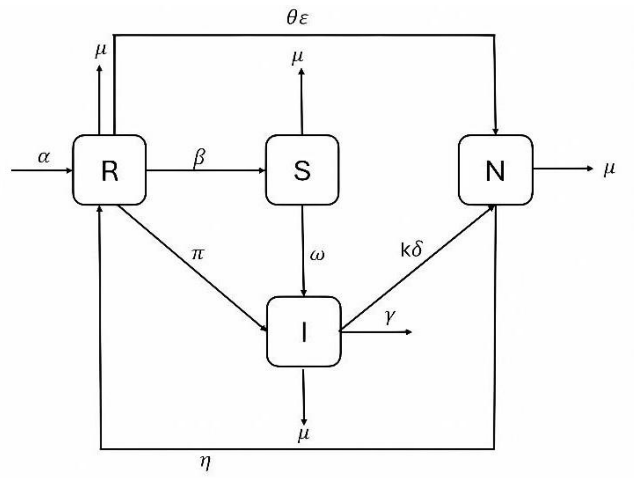

Fig 1. Compartment Diagram of Stunting Model in Children under-five in Central Kalimantan

Based on Figure 1, the proportion of children under five at risk of stunting is influenced by the proportion of children under five who have just entered group R with an entry rate of α and exit group R due to natural death of μ, move to group S because their status changes to stunting with a transfer rate of β, move to group I to receive nutritional intervention at a rate of π, and move to group P because some children under five at risk of stunting who were successfully prevented from becoming stunted due to the influence of the level of nutritional intervention θ and the effectiveness of nutritional intervention, namely ε. Children under five who have returned to normal and are at risk of stunting again at a rate of τ will increase the proportion of children under five in group R. Furthermore, the proportion of stunted children under five is influenced by the proportion of children under five who move from group R to S because their status changes to stunting at a rate of β, move from S to I to receive nutritional intervention at a rate of ω, and the presence of natural death of stunted children under five with a mortality rate of μ.

The proportion of children under five who move from group R to I to receive nutritional intervention of π and children under five who move from S to I to receive nutritional intervention at a rate of ω will increase the proportion of children under five in group I; conversely, group I will decrease in proportion along with the increase in the proportion of children under five at risk of stunting (k) who successfully recover from the risk of stunting with a recovery rate of δ and natural deaths of children under five in group I at a rate of μ and the exit of children under five from group I because they have passed the age limit of 5 years at a rate of γ. The increase in the proportion of children under five at risk of stunting (k) who have successfully returned to normal with a recovery rate of δ and the proportion of children under five at risk of stunting who are successfully prevented from becoming stunted due to the influence of the level of nutritional intervention θ and the effectiveness of nutritional intervention, namely ε, are factors that increase group N. Conversely, the existence of natural deaths of children under five in group N at a rate of μ and children under five who move from group N back to group R because they are again at risk of stunting with a rate of τ will reduce the proportion of children under five in group P.

Based on the diagram in Figure 1, the appropriate mathematical model to describe the dynamics of stunting in children under five in Central Kalimantan with the influence of nutritional intervention is as in System (1).

$$\begin{aligned} \frac{dR}{dt} &= \alpha - \beta R - \pi R - \theta\varepsilon R - \mu R + \tau N \\ \frac{dS}{st} &= \beta R - \omega S - \mu S \\ \frac{dI}{dt} &= \pi R + \omega S - k\delta I - \mu I - \gamma I \\ \frac{dN}{dt} &= k\delta I + \theta\varepsilon R - \mu N - \tau N \end{aligned} \tag{1}$$

2.2 Equilibrium Point

In this section, the equilibrium point of the model will be determined. This equilibrium point is useful for analysing conditions where the system is in a stable state, meaning there is no change in the number of individuals in each group $\frac{dR}{dt} = 0, \frac{dS}{dt} = 0, \frac{dI}{dt} = 0, \frac{dN}{dt} = 0$. Thus, the long-term condition of the system can be known. System (1) has no free stunting equilibrium $(S = 0)$ because there is no solution that satisfies the equation. In epidemiology, this shows that stunting is always present in a population even though with a certain prevalence. This system only has a stunting equilibrium point, namely a condition where there are children under five who experience stunting $(S \neq 0)$. Based on the calculation results, the equilibrium point of this stunting model $E^* = (R^*, S^*, I^*, N^*)$ is obtained, which

$$\begin{aligned} R^* = {} & \alpha(\delta k\mu 2 + \delta k\mu\omega + \delta k\mu\tau + \delta k\omega\tau + \gamma\mu 2 + \gamma\mu\omega + \gamma\mu\tau + \gamma\omega\tau + \mu 3 + \mu 2\omega + \mu 2\tau \\ & +\mu\omega\tau)/(\beta\delta k\mu 2 + \beta\delta k\mu\omega + \beta\delta k\mu\tau + \beta\gamma\mu 2 + \beta\gamma\mu\omega + \beta\gamma\mu\tau + \beta\gamma\omega\tau + \beta\mu 3 + \beta\mu 2\omega \\ & +\beta\mu 2\tau + \beta\mu\omega\tau + \delta\varepsilon k\mu 2\theta + \delta\varepsilon k\mu\omega\theta + 2\delta k\mu 3 + 2\delta k\mu 2\omega + 2\delta k\mu 2\tau + 2\delta k\mu 2\tau \\ & +2\delta k\mu\omega\tau - \delta k\mu\pi\tau - \delta k\omega\pi\tau + \varepsilon\gamma\mu 2\theta + \varepsilon\gamma\mu\omega\theta + \varepsilon\mu 3\theta + \varepsilon\mu 2\omega\theta + 2\gamma\mu 3 + 2\gamma\mu 2\omega \\ & +2\gamma\mu 2\tau + 2\gamma\mu\omega\tau + 2\mu 4 + 23\omega + 23\tau + 2\mu 2\omega\tau) \end{aligned}$$

$$\begin{aligned} S^* = {} & \alpha\beta(\delta k\mu + \delta k\tau + \gamma\mu + \gamma\tau + \mu 2 + \mu\tau)/(\beta\delta k\mu 2 + \beta\delta k\mu\omega + \beta\delta k\mu\tau + \beta\gamma\mu 2 + \beta\gamma\mu\omega \\ & +\beta\gamma\mu\tau + \beta\gamma\omega\tau + \beta\mu 3 + \beta\mu 2\omega + \beta\mu 2\tau + \beta\mu\omega\tau + \delta\varepsilon k\mu 2\theta + \delta\varepsilon k\mu\omega\theta + 2\delta k\mu 3 \\ & +2\delta k\mu 2\omega + 2\delta k\mu 2\omega\tau + 2\delta k\mu\omega\tau - \delta k\mu\pi\tau - \delta k\omega\pi\tau + \varepsilon\gamma\mu 2\theta + \varepsilon\gamma\mu\omega\theta + \varepsilon\mu 3\theta \\ & +\varepsilon\mu 2\omega\theta + 2\gamma\mu 3 + 2\gamma\mu 2\omega + 2\gamma\mu 2\tau + 2\gamma\mu\omega\tau + 2\mu 4 + 23\omega + 23\tau + 2\mu 2\omega\tau) \end{aligned}$$

$$\begin{aligned} I^* = {} & \alpha(\beta\mu\omega + \beta\omega\tau + \mu 2\pi + \mu\omega\pi + \mu\pi\tau + \omega\pi\tau)/(\beta\delta k\mu 2 + \beta\delta k\mu\omega + \beta\delta k\mu\tau + \beta\gamma\mu 2 \\ & +\beta\gamma\mu\omega + \beta\gamma\mu\tau + \beta\gamma\omega\tau + \beta\mu 3 + \beta\mu 2\omega + \beta\mu 2\tau + \beta\mu\omega\tau + \delta\varepsilon k\mu 2\theta + \delta\varepsilon k\mu\omega\theta \\ & +2\delta k\mu 3 + 2\delta k\mu 2\omega + 2\delta k\mu 2\tau + 2\delta k\mu\omega\tau - \delta k\mu\pi\tau - \delta k\omega\pi\tau + \varepsilon\gamma\mu 2\theta + \varepsilon\gamma\mu\omega\theta \\ & +\varepsilon\mu 3\theta + \varepsilon\mu 2\omega\theta + 2\gamma\mu 3 + 2\gamma\mu 2\omega + 2\gamma\mu 2\tau + 2\gamma\mu\omega\tau + 2\mu 4 + 23\omega + 23\tau \\ & +2\mu 2\omega\tau) \end{aligned}$$

$$\begin{aligned} N^* = {} & \alpha(\beta\delta k\omega + \delta\varepsilon k\mu\theta + \delta\varepsilon k\omega\theta + \delta k\mu\pi + \delta k\omega\pi + \varepsilon\gamma\mu\theta + \varepsilon\gamma\omega\theta + \varepsilon\mu 2\theta + \varepsilon\mu\omega\theta)/ \\ & (\beta\delta k\mu 2 + \beta\delta k\mu\omega + \beta\delta k\mu\tau + \beta\gamma\mu 2 + \beta\gamma\mu\omega + \beta\gamma\mu\tau + \beta\gamma\omega\tau + \beta\mu 3 + \beta\mu 2\omega + \beta\mu 2\tau \\ & +\beta\mu\omega\tau + \delta\varepsilon k\mu 2\theta + \delta\varepsilon k\mu\omega\theta + 2\delta k\mu 3 + 2\delta k\mu 2\omega + 2\delta k\mu 2\tau + 2\delta k\mu\omega\tau - \delta k\pi\tau \\ & -\delta k\omega\pi\tau + \varepsilon\gamma\mu 2\theta + \varepsilon\gamma\mu\omega\theta + \varepsilon\mu 3\theta + \varepsilon\mu 2\omega\theta + 2\gamma\mu 3 + 2\gamma\mu 2\omega + 2\gamma\mu 2\tau + 2\gamma\mu\omega\tau \\ & +2\mu 4 + 2\mu 3\omega + 2\mu 3\tau + 2\mu 2\omega\tau) \end{aligned}$$

2.3 Stability of Stunting Equilibrium Point

The next mathematical analysis is to determine the stability of the stunting equilibrium point. First, the Jacobian matrix is determined by using the partial derivatives of each function against each variable. The Jacobian Matrix is:

$$J_{(E^*)} = \begin{bmatrix} -(\beta+\pi+\theta\varepsilon+\mu) & 0 & 0 & -\tau \\ \beta & -(\omega+\mu) & 0 & 0 \\ \pi & \omega & -(k\delta+\mu+\gamma) & 0 \\ \theta & 0 & k\delta & -(\mu+\tau) \end{bmatrix}$$

Next, the characteristic equation of the Jacobian Matrix is determined, which is obtained by $J_E* - \lambda I = 0$. The characteristic equation is in the form of polinomials as follows:

$$a_0\lambda^4 + a_1\lambda^3 + a_2\lambda^2 + a_3\lambda + a_4 = 0$$

with

$a_0 = 1,$

$a_1 = \beta + \delta k + \varepsilon\theta + \gamma + \omega + \pi + \tau + 4\mu,$

$a_2 = \beta\delta k + \beta\gamma + 3\beta\mu + \delta\varepsilon k\theta + 3\delta k\mu + \varepsilon\gamma\theta + 3\varepsilon\mu\theta + \varepsilon\omega\theta + 3\gamma\mu + 6\mu 2 + \omega\pi + \omega\tau + \pi\tau$
$+3\mu\omega + 3\mu\pi + 3\mu\tau,$

$a_3 = 2\beta\delta k\mu + \beta\delta k\omega + \beta\delta k\tau + 2\beta\gamma\mu + \beta\gamma\omega + \beta\gamma\tau + 3\beta\mu 2 + 2\beta\mu\omega + 2\beta\mu\tau + \beta\omega\tau$
$+2\delta\varepsilon k\mu\theta + \varepsilon k\omega\theta + 3\delta k\mu 2 + 2\delta k\mu\omega + 2\delta k\mu\pi + 2\delta k\mu\tau + \delta k\omega\pi + \delta k\omega\tau + 2\varepsilon\gamma\mu\theta$
$+\varepsilon\gamma\omega\theta + 3\varepsilon\mu 2\theta + 2\varepsilon\mu\omega\theta + 3\gamma\mu 2 + 2\gamma\mu\omega + 2\gamma\mu\pi + 2\gamma\mu\tau + \gamma\omega\pi + \gamma\omega\tau + \gamma\pi\tau$
$+4\mu 3 + 3\mu 2\omega + 3\mu 2\pi + 3\mu 2\tau + 2\mu\omega\pi + 2\mu\omega\tau + 2\mu\pi\tau,$

$a_4 = \beta\delta k\mu 2 + \beta\delta k\mu\omega + \beta\delta k\mu\tau + \beta\gamma\mu 2 + \beta\gamma\mu\omega + \beta\gamma\mu\tau + \beta\gamma\omega\tau + \beta\mu 3 + \beta\mu 2\omega + \beta\mu 2\tau$
$+\beta\mu\omega\tau + \delta\varepsilon k\mu 2\theta + \delta\varepsilon k\mu\omega\theta + \delta k\mu 3 + \delta k\mu 2\omega + \delta k\mu 2\pi + \delta k\mu 2\tau + \delta k\mu\omega\pi + \delta k\mu\omega\tau$
$+\varepsilon\gamma\mu 2\theta + \varepsilon\gamma\mu\omega\theta + \varepsilon\mu 3\theta + \varepsilon\mu 2\omega\theta + \gamma\mu 3 + \gamma\mu 2\omega + \gamma\mu 2\pi + \gamma\mu 2\tau + \gamma\mu\omega\pi + \gamma\mu\omega\tau$
$+\gamma\mu\pi\tau + \gamma\omega\pi\tau + \mu 4 + \mu 3\omega + \mu 3\pi + \mu 3\tau + \mu 2\omega\pi + \mu 2\omega\tau + \mu 2\pi\tau + \mu\omega\pi\tau.$

Based on the Routh-Hurwitz stability criterion, the stunting equilibrium point (R^*, S^*, I^*, N^*) will be locally asymptotically stable if $a_0 > 0$, $a_1 > 0$, $a_2 > 0$, $a_3 > 0$, $a_4 > 0$, $a_1a_2 - a_3 > 0$, and $(a_1a_2 - a_3)a_3 - a_1^2a_4 > 0$ [19].

2.4 Numerical Simulation and Analysis of the Effect of Local Based Food Nutritional Intervention on Stunting Dynamics in Central Kalimantan

Model simulations were performed using Python programming. We use initial values of variables to simulate this model (1) based on data obtained from the Central Kalimantan TPPS as presented in Table 1. We use stunting prevalence data from 2022.

Table 1. Initial Values of Variables

Variables	Symbol	Initial Value	References
The proportion of children under five at risk of stunting	R	0,3252	(20)
The proportion of stunted children under five	S	0,269	(21)
The proportion of children under five receiving nutritional interventions	I	0,264695	(20)
The proportion of children under five at risk of stunting who successfully become normal after receiving nutritional intervention.	N	0,19	(20)

The parameter values in the model mostly use the results of parameter estimates based on available data; only a small part uses general assumptions about related stunting data. Table 2 presents these parameter values.

Table 2. Parameter Values in the Mathematical Model of Stunting with Nutritional Intervention

Parameters	Symbol	Parameter Value	Value Type
The rate of entry of new children under five into group R	α	0,0168	Estimate value
The rate of children under five transition to stunting	β	0,00692	Estimate value
The rate of natural death	μ	0,081	Estimate value
The rate of transition of children under five from group R to I	π	0,011	Estimate value
The coverage of nutritional interventions	θ	0,7	Estimate value
The effectiveness of nutritional interventions	ε	0,3	Estimate value
The rate of children under five movement from group P to R	τ	0,01	Assumption value
The rate of transition of children under five from group S to I	ω	0,3	Assumption value
The proportion of children under five at risk of stunting who successfully recover	k	0,2	Estimate value
The rate of recovery	δ	0,1912	Estimate value
The rate of children under five leaving group I because they have passed the age limit of 5 years	γ	0,2	Assumption value

Before conducting model simulations to analyze the effect of local food on stunting prevalence, we conducted numerical simulations to analyze the stability of the stunting equilibrium point according to existing conditions in Central Kalimantan. Based on the parameter values in Table 2, system (1) can be rewritten as:

$$
\begin{aligned}
\frac{dR}{dt} &= 0{,}0168 - 0{,}30892\mathrm{R} - 0{,}01\mathrm{N} \\
\frac{dS}{st} &= 0{,}00692\mathrm{R} - 0{,}381\mathrm{S} \\
\frac{dI}{dt} &= 0{,}011\mathrm{R} + 0{,}3\mathrm{S} - 0{,}3192\mathrm{I} \\
\frac{dN}{dt} &= 0{,}21\mathrm{R} + 0{,}03824\mathrm{R} - 0{,}091
\end{aligned} \tag{2}
$$

With initial values (Table 1), $R(0) = 0{,}3252, S(0) = 0{,}269, I(0) = 0{,}264695$, and $N(0) = 0{,}19$ so that the Jacobian matrix of System (2) becomes:

$$
J_{(f)} = \begin{bmatrix} -0{,}30892 & 0 & 0 & -0{,}01 \\ 0{,}00692 & -0{,}381 & 0 & 0 \\ 0{,}011 & 0{,}3 & -0{,}31924 & 0 \\ 0{,}21 & 0 & 0{,}03824 & -0{,}091 \end{bmatrix}
$$

The eigenvalues obtained for the characteristic equation of the Jacobian matrix are: $-0{,}10126874495907229$; $-0{,}29584529038954854$; $-0{,}32261679576948715$, and $-0{,}38042916888189204$. Since all of real part of eigenvalues are negative, the stunting equilibrium point of system (1) is locally asymptotically stable.

Another way to analyze the stability of equilibrium points is by using the Routh-Hurwitz Criteria. According to the Routh-Hurwitz Criteria, the following requirements must be fulfilled:

$$a_0 > 0, a_1 > 0, a_2 > 0, a_3 > 0, a_4 > 0, a_1a_2 - a_3 > 0, \text{and } (a_1a_2 - a_3)a_3 - {a_1}^2a_4 > 0.$$

Based on the results of Python's calculations using the parameter values in Table 2, the coefficient values are:
$a_0 = 1$,
$a_1 = 1.10016$,
$a_2 = 0.28606190079999994$,
$a_3 = 0.0668196859776$,
$a_4 = 0.003161420447956799$, and
$a_1a_2 - a_3 = 0.22532556610541005$,
$(a_1a_2 - a_3)a_3 - {a_1}^2a_4 = 0.05138393947026817$.

These values fulfilled the Routh-Hurwitz Criteria. Thus, the stunting equilibrium point of system (1) is locally asymptotically stable, indicating that stunting still exists in the population but is under control, its prevalence tends to remain at a certain level.

Next, simulation of model was conducted on each compartment with three scenarios to compare the effectiveness of nutritional interventions. First scenario is without nutritional intervention, the second is with local food-based nutritional intervention except snakehead fish and moringa leaves, and the last is scenario with local food-based nutritional intervention using snakehead fish and moringa leaves. The simulation was carried out for a period of 10 years. The simulation results are shown in Figure 2.

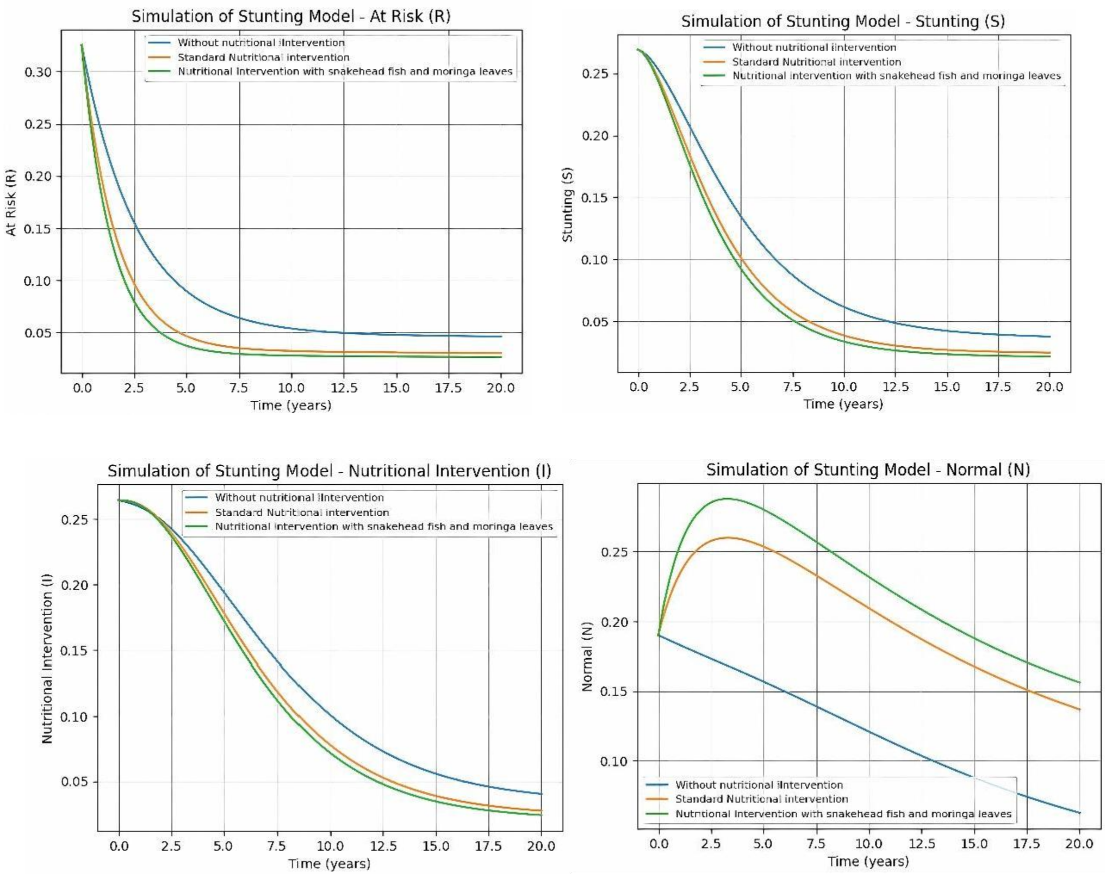

Fig 2. Simulation of Stunting Dynamic in Central Kalimantan with Nutritional Intervention and Without Nutritional Intervention

Figure 2 is the result of a model simulation showing the dynamics of stunting in children under five in Central Kalimantan by considering nutritional interventions and recovery. The simulation was carried out with three scenarios: without nutritional intervention ($\pi = 0, \theta = 0, \varepsilon = 0$), with local food-based nutritional interventions except snakehead fish and moringa leaves ($\pi = 0.011, \theta = 0.7, \varepsilon = 0.30$), and with local food-based nutritional interventions, snakehead fish and moringa leaves ($\pi = 0.011, \theta = 0.7, \varepsilon = 0.435$).

The value of $\varepsilon = 0.30$ in the second scenario shows the effectiveness value of general nutritional interventions that have been carried out so far, including the Provision of Additional Food (PMT) with local food ingredients that are commonly given and consumed by the community, such as eggs, chicken, fish, vegetables, etc. This value is adopted from the general information that specific nutritional interventions contribute 30% to reducing stunting prevalence [22]. The third scenario is the condition if nutritional interventions are implemented with the Provision of Additional Food (PMT) or supplements made from snakehead fish and moringa leaves. The value of $\varepsilon = 0.435$ is the combined estimated value obtained based on the results of the study [23] that 37% of children who successfully recovered from stunting after receiving fish-based nutritional supplements and around 50% of children who were tested successfully improved their nutritional status after regularly consuming moringa leaves [9], assuming that 50% of each of the two local food items are consumed.

This value is assumed to be relevant when applied in Central Kalimantan.

The simulation results (Figure 2) show a significant difference between changes in the proportion of children under-five in each compartment over time with and without nutritional intervention. In group R (at risk of stunting), it can be seen that the proportion of children under-five at risk of stunting decreases more quickly if given nutritional intervention, especially if given nutritional intervention based on snakehead fish and moringa leaves. Likewise, in group S (stunting), the decrease in stunting prevalence is faster with nutritional intervention than without nutritional intervention. This decrease becomes even faster if nutritional intervention is carried out by providing food supplements made from snakehead fish and moringa leaves. It can be seen in the initial conditions, when the prevalence of stunting in Central Kalimantan in 2022 was 26.9% $(t = 0)$; a year later $(t = 1)$, it decreased to around 24%. This figure is close to the reality that in 2023 the prevalence of stunting in Central Kalimantan managed to decrease to 23.5%. Meanwhile, in the following year $(t = 2)$, it is predicted that the prevalence of stunting will decrease to 20%. In group I (nutritional intervention), the proportion of children under-five receiving nutritional intervention decreased faster compared to the scenario without nutritional intervention, especially if given snakehead fish and moringa leaves. This decrease is in line with the decrease in the prevalence of stunting. Furthermore, in group N (Normal), the proportion of children under five who recovered from the risk of stunting was higher in the scenario with local food-based nutritional intervention, with snakehead fish and moringa leaves, followed by nutritional intervention and without nutritional intervention. Overall, the simulation results show that local food-based nutritional intervention is very helpful in reducing the prevalence of stunting, especially in Central Kalimantan.

3 Conclusions

There are many conclusion based on the results and analysis: 1) this mathematical model shows that local food-based nutritional interventions have a positive effect on reducing the prevalence of stunting in Central Kalimantan, 2) based on model simulations, it may be concluded that broader and more extensive nutritional interventions reduce child stunting in Central Kalimantan, 3) using locally available foods, like snakehead fish and moringa leaves, in nutritional treatments has the potential to improve their efficacy and accelerating the reduction in the prevalence of stunting.

We advise the regional government of Central Kalimantan to expand the reach and intensity of locally based food-based nutritional treatments, particularly for children at risk of stunting, optimizing the most of local food in nutritional intervention programs, such as snakehead fish and moringa leaves, and strengthening community outreach and education programs on the value of a balanced diet and the usage of locally grown food to prevent stunting. As for further research, it is recommended to add other factors that can affect stunting, such as control of pregnant women and immunization of toddlers so that the model becomes more relevant in describing the dynamics of stunting in Central Kalimantan.

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