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An Optimization Approach for Estimating Food Demand to Support Supply Chain Management in North Maluku Province

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ABSTRACT: This study aims to estimate food requirements to support supply chain management in North Maluku Province. A survey method was employed to gather data on population, as well as consumption levels and patterns. Population growth was projected using a logistic model with a limiting constant, while food requirements were analyzed via a linear optimization approach, with an objective function targeting a consumption level of at least 2,200 kcal. Recommended Dietary Allowances (RDA) and food type proportions served as constraint functions. Estimating food requirements based on population growth and consumption patterns proved feasible through a linear approach, yielding a relatively low relative bias of 0.2%. The resulting estimates can be used to determine the magnitude of future deficits, assuming production rates remain constant. Projections for 2024 indicate a food deficit particularly for rice of 45,207.54 tons (approximately 72%), a figure expected to rise annually absent any increase in production. Consequently, sourcing food from outside the region is essential, and the food supply chain management process will benefit from the estimates generated in this study.

KEYWORDS: Estimation, linear optimization, food requirements, North Maluku

1. INTRODUCTION

Food security is an integrated food economic system comprising various subsystems[1]. It encompasses at least two fundamental elements: sufficient food availability and adequate public access to food both of which are essential for achieving public health and well-being. Food security constitutes a unified whole encompassing the dimensions of availability, accessibility, and price stability[2]. The Food Security Council (DKP), in collaboration with the World Food Programme (WFP), has formulated food security indicators categorized into three factors: availability, access, and utilization[3]. Thus, the food security system can be described as consisting of three primary subsystems: availability, access, and food absorption. Food availability must be sufficient to meet needs, defined as the caloric intake required for an active and healthy life[1].

Food distribution in archipelagic regions remains inefficient in reaching all consumer areas, particularly in regions facing supply challenges during specific periods. The lack of established village-level food granaries contributes to low food availability, access, and consumption at the household and individual levels. Many archipelagic areas still struggle with transportation infrastructure, information systems, food stock procurement, market development, and the security of food distribution routes.

Information flow as a fundamental element of supply chain management must be prioritized and is crucial for the planning and execution of supply chain operations. A key piece of information in the logistics distribution of strategic commodities (such as food) is the projected demand for each specific region. This study aims to estimate food requirements for each region in North Maluku Province, providing dynamic information to support food supply chain management.

2. REVIEW OF LITERATURE

Food Consumption

Food utilization refers to the use of food to meet healthy living requirements, encompassing energy and nutritional needs, water, and environmental health. The effectiveness of food utilization depends on household or individual knowledge, sanitation and water availability, health facilities and services, as well as nutrition education and toddler care. Food utilization encompasses both the household's use of food and the individual's physiological capacity to absorb and metabolize nutrients[3].

Assessments of ideal food consumption are based on Recommended Dietary Allowances (RDA), which include caloric adequacy (exceeding 2,000 kcal/capita/day) and protein adequacy; regarding the latter, the WHO has recommended an ideal protein intake for adults of 0.6 g/kg of body weight since 1985. However, alongside the trend toward healthy lifestyles, the contribution of protein to energy supply has risen in tandem with increased protein consumption. A study by the New Zealand Ministry of Health (2003) recorded an increase in the proportion of protein contributing to energy intake from 14% to 16% over a 20-year period[4].

Food consumption and dietary patterns depend heavily on the types of food available and accessible on a continuous basis; consequently, dietary patterns vary by region. According to Djojomartono *et al.*, a crucial factor influencing the food supply system is the production system, specifically the availability of land for production. Land used for rice production includes irrigated fields (categorized by technical, non-technical, or simple irrigation systems), rain-fed fields, tidal-influenced fields, and other types of paddy land. Due to infrastructure development requiring extensive land areas, some regions have experienced land-use conversion from agriculture to non-agricultural purposes, such as industrial activities, housing, and road construction[5].

The other determining factors in the food production system include climatic stress, productivity (varieties), technology adoption, cropping intensity (IP), pest infestations, and natural disasters such as floods or droughts[6]. These components likely interact within their own subsystems or with components outside those subsystems. The food demand subsystem comprises requirements for direct consumption, the food industry, and seed stock. Consumption needs constitute the largest share of total demand, a component influenced by population growth rates, consumption levels, and the diversification of consumption habits within the community.

In archipelagic regions characterized by scattered small islands and limited land-carrying capacity, where water scarcity, thin soil layers, and rocky substrates pose challenges for developing rice-based food commodities is difficult. Under these environmental conditions, to meet carbohydrate needs, farmers opt for crops that are relatively resistant to water stress and thrive in thin soil profiles, such as cassava.

Long-standing environmental pressures have shaped lifestyles and consumption patterns over generations, giving rise to local wisdom regarding food. This wisdom manifests as a diversification of carbohydrate sources beyond rice that could be practices evident in both daily life and traditional ceremonies, such as those found in the South Halmahera islands.

Conversely, these archipelagic regions are rich in marine and coastal resources, particularly seafood (fish, shrimp, and shellfish). Consequently, it is unsurprising that data on food consumption patterns in South Halmahera show rice consumption levels below the national average, while fish consumption figures are significantly higher than the national average.

Estimation of Food Requirements

Food requirements are calculated based on the individual consumption of the population residing in a specific area. Various methods are frequently used to analyze individual consumption patterns, including the NCI (National Cancer Institute) method developed by Janet *et al.*, which calculates daily consumption levels based on individual intake over a 24-hour cycle[7], and the LNN (Logistic-Normal-Normal) method developed by Tooze *et al*. However, for multi-food consumption or intake, suggest that the "Model-Then-Add" approach is suitable due to the correlations between the types of food consumed and diverse consumption patterns[8].

Linear Programming for Optimizing Food Requirements

Optimization aims to enhance efficiency by utilizing limited resources to achieve specific goals. An optimization model comprises at least two elements namely an objective function and constraint functions as expressed mathematically and incorporating values relevant to decision-making[9].

3. RESEARCH METHODS

This study employed a survey method involving observation and limited interviews, conducted from April to July 2025 in North Maluku Province. The data required to estimate food requirements consisted of population trends over the preceding five years and per capita food expenditure and consumption data from the most recent year (2024). The collected data were subsequently processed according to the study's food requirement estimation flowchart shown in Figure 1.

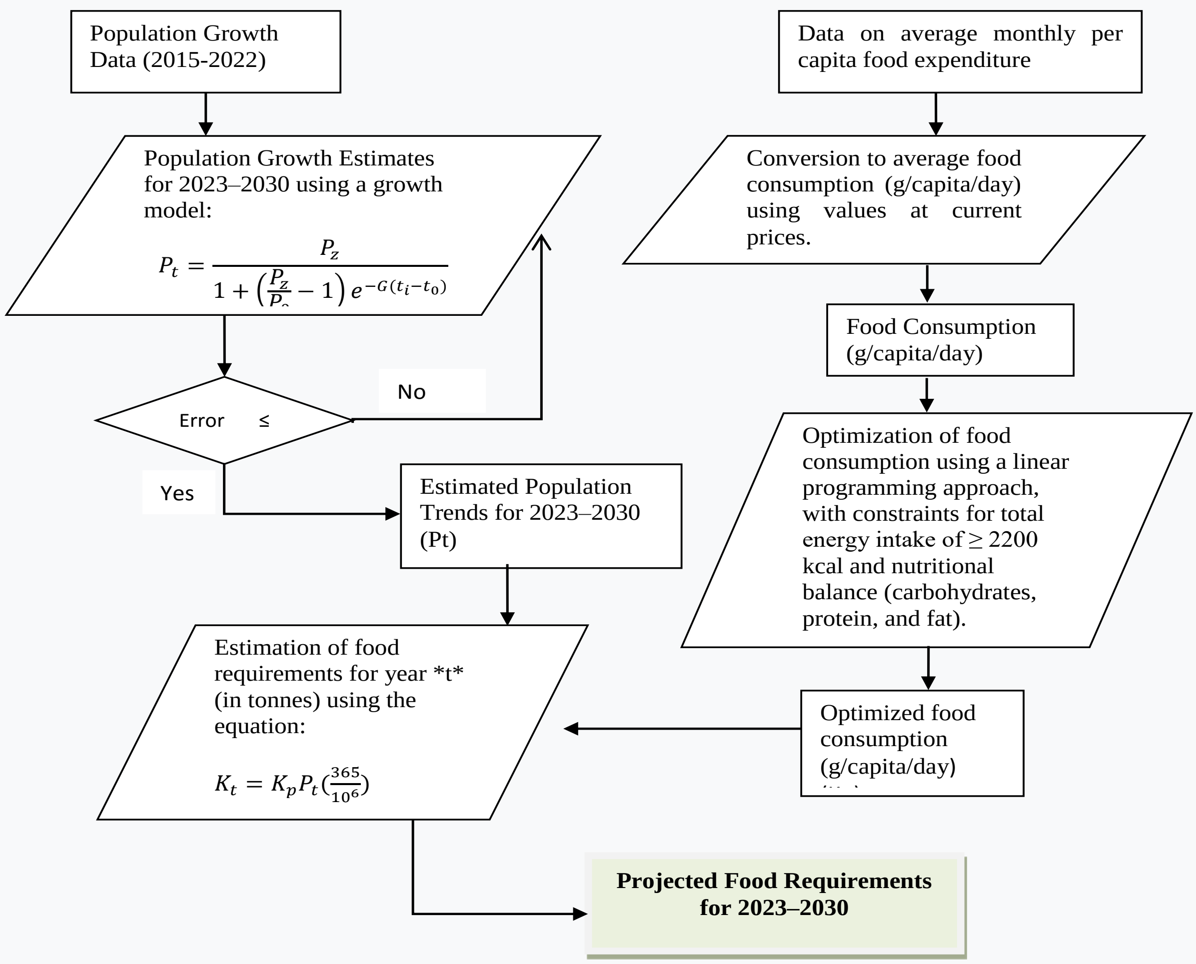

Fig.1 Flowchart for estimating food requirements.

4. RESULT AND DISCUSSION

The level of consumption or expenditure by a household reflects its welfare status. Higher household expenditure on non-food items indicates an improvement in the household's welfare. As a benchmark, if the proportion of expenditure on food exceeds 60 percent of total expenditure, the level of welfare is considered low. Generally, a higher proportion of expenditure allocated to food consumption results in reduced spending on health, education, and other areas. The per capita expenditure of the South Halmahera population shows a ratio of 53:47 between food and non-food spending. This indicates that expenditure priorities are focused on meeting the most basic need: food. Furthermore, Table 1 presents per capita consumption of various food items in grams.

Table 1. Average Monthly Per Capita Consumption by Food Group in North Maluku Province, 2024[10]

Foods	Consumption (g)
Rice	125
Corn	25
Wheat	35
Tubers	125
Nuts	15
Meat	25
Egg	25

Fish	135
Milk	25
Vegetables	60
Fruits	26
Fat/Oil	15

The largest proportions of food consumption are found in the cereals, tubers, and fish groups. The food groups accounting for the largest shares of caloric intake are cereals, tubers, fish, and oils and fats. The composition of carbohydrates, protein, and fat is presented in Table 2.

Table 2. Composition of carbohydrates, fats, and proteins

	Energy Content (kcal/g)		
	C.hydrate	Fat	Protein
Rice	3.40	0.10	0.24
Corn	3.08	0.17	0.25
Wheat	2.92	0.08	0.32
Tubers	0.54	0.02	1.72
Nuts	1.01	1.40	1.40
Meat	1.43	2.44	0.48
Egg	0.03	1.38	0.57
Fish	2.26	1.98	1.56
Milk	2.35	2.13	0.50
Vegetables	0.10	0.03	0.03
Fruits	0.86	0.03	0.00
Fat/Oil	0.00	8.75	0.00

Source: Soedioetama, 1976 and Krisno, 2002.

Population Growth Projection

To maintain adequate food availability, inventory management requires sound planning. This is achievable when food requirements for specific periods can be accurately estimated. Various methods are commonly employed to forecast food needs (typically utilizing trends in population growth and public consumption patterns).

Population data for North Maluku Province from 2015 to 2022 served as the basis for estimating population growth for the 2023–2030 period. These estimates were generated using a logistic growth model commonly known as the Pearl-Reed curve[11]. This curve is a modification of the exponential curve, and the following equation form is most frequently used:

$$P_t = \frac{P_z}{1 + \left(\frac{P_z}{P_0} - 1\right) e^{-G(t_i - t_0)}}$$

where

Pz = Maximum population (assumed to be 10,000,000 people)

Po = Initial population (2015)

G = Growth constant (=1.455)

t = Time (years)

In this form, the logistic curve always has an upper limit, Pz, and G as a negative constant. This equation is used to estimate the population for future years, assuming a constant growth rate. Table 3 presents data on the population of North Maluku from 2015 to 2022, based on BPS (2025) data and estimation results.

Table 3. Population of North Maluku, 2015–2022

Year	2015	2016	2017	2018	2019	2020	2021	2022
Actual population	184620	187482	190388	193339	196340	198911	203707	206873
Population Estimation Results	184620	187602	190620	193676	196770	199900	203067	206272

The deviation value of the estimate, amounting to 207.8 or 0.1%, indicates that the model is suitable for making estimates for the following year. The estimated population growth for North Maluku Province for the period 2023–2030 is presented in Table 4

Table 4. Population estimates for North Maluku Province, 2023–2030

Tahun	2023	2024	2025	2026	2027	2028	2029	2030
Estimasi Penduduk	209513.4	212792.5	216108.9	219462.6	222853.5	226281.6	229746.9	233249.3

Estimation of Food Requirements

Individual consumption levels and patterns serve as the basis for calculating the population's food requirements over a specific period. To achieve a more ideal estimate of food requirements, an optimization process was conducted with the objective of meeting a total energy consumption target of 2,200 kcal/capita/day. Constraints were established to ensure nutritional adequacy and balance, specifically regarding the proportional ranges (%) for carbohydrate, fat, and protein consumption: 30–60%, 0–25%, and 10–30%, respectively. Additional constraints involved the proportions of specific food products or types, adjusted to align with existing consumption patterns. The resulting data is presented in Table 5.

Table 5. Optimization results for an energy requirement of 2,200 kcal/capita/day.

Daily Energy	2200										
Optimized	2200										
Foods	Energy Content (kcal/g)			Amount (g)	Energy (kcal)					Production Constraint	
	Chydr ate	Fat	Protein		Chydr ate	Fat	Protein	Total	Proporsi	Min (%)	Max (%)
Rice	3.40	0.10	0.24	**124**	422	12	30	465	21%	25	35%
Corn	3.08	0.17	0.25	**25**	76	4	6	86	4%	3	9%
Wheat	2.92	0.08	0.32	**34**	100	3	11	114	5%	1	3%
Tubers	0.54	0.02	1.72	**125**	67	2	214	284	20%	15	20%
Nuts	1.01	1.40	1.40	**14**	14	20	20	54	2%	1	3%
Meat	1.43	2.44	0.48	**24**	35	60	12	107	5%	1	10%
Egg	0.03	1.38	0.57	**25**	1	34	14	49	2%	1	15%
Fish	2.26	1.98	1.56	**134**	302	265	209	776	35%	25	40%
Milk	2.35	2.13	0.50	**24**	56	50	12	118	5%	3	8%
Vegetables	0.10	0.03	0.03	**60**	6	2	2	10	0%	1	5%
Fruits	0.86	0.03	0.00	**26**	22	1	0	23	1%	1	5%
Fat/Oil	0.00	8.75	0.00	**13**	0	115	0	115	5%	1	3%
	Energy			Total (kcal)	1102	569	529	2200			
				Percenta ge	50%	26%	24%				
	Health Constraint			Max (%)	60%	25%	30%				
				Min (%)	30%	0%	10%				

The results in the "Amount (g)" column of Table 5 were then used to estimate annual food requirements. The calculation results are presented in Table 6.

Table 6 Estimated food requirements for North Maluku (in tonnes) for the years 2023–2030

Foods	(g/ cap. day)	*Food requirements for North Maluku* (ton)							
		2023	2024	2025	2026	2027	2028	2029	2030
Rice	124	60,537	61,461	62,386	63,310	64,234	65,159	66,083	67,007
Corn	25	12,205	12,391	12,578	12,764	12,950	13,137	13,323	13,510
Wheat	34	16,599	16,852	17,106	17,359	17,613	17,866	18,120	18,373
Tubers	125	61,025	61,957	62,889	63,821	64,752	65,684	66,616	67,548
Nuts	14	6,835	6,939	7,044	7,148	7,252	7,357	7,461	7,565
Meat	24	11,717	11,896	12,075	12,254	12,432	12,611	12,790	12,969
Egg	25	12,205	12,391	12,578	12,764	12,950	13,137	13,323	13,510
Fish	134	65,419	66,418	67,417	68,416	69,415	70,413	71,412	72,411
Milk	24	11,717	11,896	12,075	12,254	12,432	12,611	12,790	12,969
Vegetables	60	29,292	29,739	30,187	30,634	31,081	31,528	31,976	32,423
Fruits	26	12,693	12,887	13,081	13,275	13,468	13,662	13,856	14,050
Fat/Oil	13	6,347	6,444	6,540	6,637	6,734	6,831	6,928	7,025

These estimates can be used for logistics planning. As shown in Table 6, several food items indicate significant demand, whereas local production capacity is very low (rice, cooking oil, egg, vegetables, legumes); indeed, some items are not produced locally at all (wheat flour and milk).

The food requirement in North Maluku, specifically for rice for 2024 stands at 61,461 tons, whereas the available supply for the same year is 17,178 tons. This means that 72% of the rice requirement must be sourced from outside the North Maluku region, this deficit figure will continue to rise to 75% by 2030 if rice production is not increased. The same applies to eggs intended for food, the demand for eggs in 2024 is 12,391 tons, whereas production is only around 6,269 tons (50.6% of the demand), and this figure will rise annually unless production is increased.

5. CONCLUSION

Optimizing the estimation of food requirements based on population growth and consumption patterns can be achieved using a linear approach with a relatively low deviation standard of 0.2%. The resulting estimates allow for the determination of projected future deficits, assuming production growth rates remain constant. Projections for 2024 indicate a food supply deficit, particularly for rice of 45,207.54 tons (approximately 72%), a figure expected to rise annually absent an increase in production. Consequently, sourcing food from outside the region becomes essential, and the estimates generated here will facilitate effective food supply chain management.

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