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Role of Roads and Irrigation on Food Security in Indonesia

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Abstract

Food security is a critical aspect of assessing people's well-being. One key factor influencing food security is infrastructure. In Indonesia, food security varies significantly, but it has remained stagnant at lower levels in the eastern regions for several years. According to regulations governing financial relations between the central and regional levels, spending on public service infrastructure should constitute 40% of the regional budget. This study examined the relationship between road infrastructure and food security. However, the study also considers irrigation development and other variables for a more comprehensive analysis. By analyzing data from 508 regencies and cities in Indonesia from 2018 to 2021, this research explores the impact of road and irrigation infrastructure on food security at the local level. The study, utilizing the Generalized Method of Moments (GMM), concludes that consistent road construction can improve food security in regencies and cities across Indonesia. Gross Regional Domestic Product (GRDP), access to sanitation, and water availability also play crucial roles in determining national food security.

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INTRODUCTION

Food security is a fundamental prerequisite for ensuring that a country can meet the nutritional needs of its population. It is characterized by the availability of food in sufficient quantity and quality. Additionally, food security is defined by the accessibility of safe, diverse, nutritious, equitable, and affordable food that aligns with religious, cultural, and societal values. Food security is vital for enabling individuals to lead healthy, active, and productive lives on a sustainable basis (FSA, 2022). Conversely, food insecurity occurs when a country fails to provide adequate food for its population. Food and Nutrition Insecurity (FNI) refers to insufficient access to food in terms of quantity and quality. FNI is a global issue that significantly impacts public health and social stability (Fagundes et al.,2022). Therefore, efforts to enhance a country's food security are crucial. Public infrastructure, which provides essential services that improve the quality of life, is key in enhancing food security to reduce poverty, which is usually synonymous with food shortages (Nagesso et al., 2019)

The Global Food Security Index (GFSI) is a reliable source for assessing global food security, developed by Economist Impact and supported by Corteva Agriscience. The GFSI evaluates food security conditions in 113 countries based on affordability, availability, quality, safety, sustainability, and adaptation. This index is compiled using a dynamic model formed from 68 quantitative and qualitative drivers of food security. In 2022, Indonesia ranked 63rd out of 113 countries, scoring 60.2. This score was below the global average of 62.2 and the Asia-Pacific average of 63.4.

Meanwhile, the Food Security Agency of the Ministry of Agriculture in Indonesia issues a Food Security Index (FSI) score. The FSI is calculated based on three aspects: food availability, food affordability, and food utilization. The FSI adopts the indicators used in the GFSI but adjusts them to fit the conditions and data available in Indonesia (FSA, 2022). In 2021, the FSI score decreased in several regencies, cities, and provinces in Indonesia compared to 2020. At the regency level, 186 regencies (44.71%) experienced a decrease in FSI scores. Meanwhile, 17 cities (17.35%) experienced a decrease in their FSI scores. Additionally, eight provinces (23.53%) experienced a decrease in the FSI score at the provincial level. This decrease is concerning because food security is fundamental to determining community welfare.

Food security is positively influenced by the availability of infrastructure (Frayne & McCordic, 2015), however, not all regions, particularly those in eastern Indonesia, have experienced improvements in food security (FSA, 2022). This disparity is reflected in the food security index scores across most regions in eastern Indonesia, which have consistently remained low since the index was first compiled at the regency, city, and provincial levels in 2018. Numerous studies have examined the impact of infrastructure on food security. Zhou et al. (2021) found that rural road construction supports the sustainable development of agriculture in 31 provinces in China, particularly in the central and eastern regions. Infrastructure development can also help alleviate poverty, which is closely linked to food insecurity. This finding is supported by Blimpo et al. (2013), who reported that areas in Benin, Ghana, Mali, and Senegal with fewer roads have higher rates of childhood stunting.

From the availability perspective, roads facilitate easier access to food from other sources, reducing food scarcity concerns and increasing food availability. However, from the affordability perspective, food insecurity may rise in areas near roads as many people invest in non-agricultural sectors. In terms of utilization, areas near roads tend to have higher consumption of carbohydrates, protein, and fats due to easier access to processed foods, leading to weight issues among both adults and children. Thus, roads are related to all three aspects of food security (Grocke & McKay, 2018).

Infrastructure development and planning can mitigate food insecurity (Frayne & McCordic, 2015), especially with the construction of irrigation infrastructure (Zainuddin, 2021; Gohar et al., 2015; Bazzana et al., 2020; Pambudi, 2021) and agricultural infrastructure (Zainuddin, 2021), which enhance land productivity (availability) and consumption (Adela et al., 2019). However, few studies have explored the combined relationship between road infrastructure, irrigation, and food security. Previous research has predominantly focused on the role of road infrastructure or public transportation in food security (Zhou et al., 2021; Makbul et al., 2019; Grocke & McKay, 2018; Baek, 2016; Blimpo et al., 2013). Irrigation is a critical factor in food security, particularly in terms of food availability through agricultural production. While numerous studies have examined the link between irrigation and food security, dam construction has been found to have both positive and negative effects on local communities and their food security. Additionally, many studies on irrigation and food security remain qualitative. Therefore, this study seeks to examine the relationship between road infrastructure, irrigation infrastructure, and food security.

Food security in Indonesia is measured using an index published by the Food Security Agency. Previous research has primarily focused on the effects at the provincial level or within specific time frames. However, analyses limited to a certain period do not adequately capture the evolving nature of food security over time or how stakeholders adjust policies. Similarly, studies with a specific geographic focus fail to provide a comprehensive overview of food security across all regions of Indonesia. This research aims to examine the role of road infrastructure on food security at the regency and city levels, a perspective that has been underexplored in prior studies. The study employs a dynamic panel data analysis method using the Generalized Method of Moments (GMM) because the food security index, composed of various indicators, is inherently dynamic, with current values influenced by those from previous periods. Additionally, this method addresses endogeneity issues, such as independent variables correlating with error terms and the problem of reverse causality, where dependent and independent variables may influence each other.

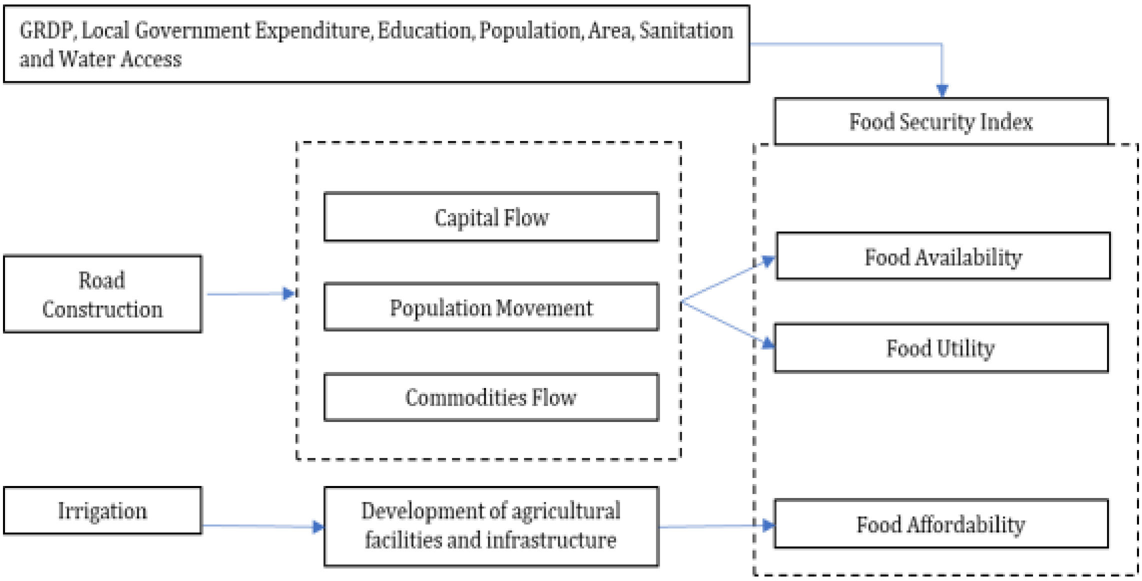
RESEARCH METHODS

Road infrastructure can influence the movement of people between regions, encouraging residents to seek employment opportunities with better availability and higher wages. The construction of rural roads can promote labor migration to urban areas and increase the productivity of workers from villages. Other resources, such as agricultural machinery, equipment, seeds, and fertilizers, have also been relocated, as illustrated in Figure 1 (Zhou et al., 2021). Consequently, road construction is expected to impact food security in terms of affordability and food utilization.

Similarly, the development of irrigation systems can enhance agricultural production, thereby improving the availability of food items such as rice, corn, cassava, and sweet potatoes. Other factors are also considered, including regional GDP, education levels, regional expenditure, access to drinking water and sanitation, and population size. The framework of this study is visually represented as follows.

To analyze the data, the researcher used descriptive and inferential analysis methods to analyze panel data from 508 regencies and cities in Indonesia between 2018 and 2021 to obtain accurate estimates and interpretations of the relationships among the variables in this study. The data employed includes information on food security indexes that will be available at the regency/city level starting in 2018. Although similar data was issued by BPS-Statistics Indonesia in previous years, it was only available at the provincial level (Food Security Agency, 2019).

The dependent variable in this research is food security, measured using the Food Security Index indicator for the years 2018-2021, as provided by the Indonesian Food Security Agency. The independent variable is infrastructure, represented by road and irrigation infrastructure during the same period. The road infrastructure data used in this study is the total length of roads, measured in kilometers, under the jurisdiction of each regency and city in Indonesia. The measurement of road infrastructure based on road length was adopted from the research conducted by Qin et al. (2022). However, the condition of regency/city roads must also be considered. Roads in good or moderate condition (steady roads) are expected to have a stronger impact on economic growth (Kartiasih, 2019; Siregar & Tanjung, 2020; Saragih & Khoirunurrofik, 2022), as these studies include variables representing road infrastructure in good or moderate condition. Irrigation infrastructure, measured by the area of irrigated land, was also adopted from research by Qin et al. (2022), which examined the influence of rural infrastructure on poverty in China. The infrastructure data was obtained from the Ministry of Public Works and Public Housing.



Source: Zhou et al., 2021 (Processed)

In this study, food security is measured from several aspects, namely availability, affordability, and utilization, with each aspect being assessed through specific indicators. Each indicator (t) in the index can be influenced by stock accumulation from the previous period (t-1). For example, regarding food availability, the ratio of normative consumption per capita to net production may be affected by public consumption and net production of various commodities (such as rice, corn, cassava, and sweet potatoes, as well as rice stocks) from the previous period. If public consumption in the previous period was lower than in the current period, assuming constant commodity production, the ratio for the current period would be higher. Conversely, if production in the previous period were either lower or higher than in the current period, it would affect the commodity stocks in the current period. Mahbubi (2014) notes that the national rice stock system, which includes supply, production, and consumption elements, is dynamic and influenced by time.

Regarding food affordability, indicators related to income and poverty might be influenced by the proportion of people below the poverty line who spent more than 65% of their total expenditure on food in the previous period (Arya, 2019). Similarly, the number of households lacking access to electricity in the current period likely reflects the accumulation of households without electricity from the previous period. Additionally, food utilization aspects use stock or quantity data, accumulations from the previous period. Relevant indicators include the education level of women over 15 years old, the percentage of households without electricity, the number of residents per health worker to population density, the number of stunted children under five, and life expectancy at birth. Ahmad et al. (2023) indicate that health outcomes, such as life expectancy at birth and healthy life expectancy, are influenced by values of these variables from the previous year. Thus, it can be concluded that all indicators in the food security index for each aspect of food security are derived from stocks or quantities from the previous period. Therefore, the food security index for the current period (t) is likely influenced by the index from the previous period (t-1). This dynamic nature makes the static panel data method unsuitable for estimating the effect of road infrastructure on the food security index.

The dynamic conditions and endogeneity problems above can be overcome by using the Arellano Bond Generalized Method of Moments (GMM). This method was first introduced by Bond and Temple (2001) by discussing the restrictions of linear moments of certain specifications and further be used with unbalanced panel data. They researched explanatory variables more deeply, which were determined but not very exogenous, resulting in serial correlation. There are several advantages of this method. First, problems of Omitted Variable Bias (OVB) can be resolved. Second, usage instrument variables make variable estimates consistent, including endogenous variables. Third, the estimates become more consistent with the use of the instrument, including any measurement error (Bond & Temple, 2001). Various conditions to choose from the moment and weighting matrices lead to different GMM estimators, and different distribution choices lead to different ML estimators. In addition, the GMM estimator also provides consistency and asymptotic normality and methods for estimating variance matrix (Cameron & Trivedi, 2005).

Therefore, the form of the regression equation to be used is as follows:

$$lnFSI_{it} = \mu_0 + \mu_1 lnFSI_{it-1} + \mu_2 lnSROAD_{it} + \mu_3 lnIRR_{it} + \mu_4 lnEDU_{it} + \mu_5 lnGDP_{it} + \mu_6 lnAREA_{it} + \mu_7 lnPOP_{it} + \mu_8 lnSANIT_{it} + \mu_9 lnWATER_{it} + \mu_{10} lnEXP_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \quad \text{.................(1)}$$

$lnFSI_{it}$ is Food Security Index in regency/city i year t; $lnFSI_{it-1}$ is lag Food Security Index in regency/city i year t-1; $lnSROAD_{it}$ is steady road length (km) in regency/city i year t; $lnIRR_{it}$ is the area of irrigation area (ha) in regency/city i year t; $lnEDU_{it}$ is average years of schooling (years) in regency/city i year t; $lnGDP_{it}$ is GDP in regency/city i year t; $lnAREA_{it}$ is an area in regency/city i year t; while $lnPOP_{it}$ is the total population in regency/city i year t; $lnSANIT_{it}$ is access to sanitation (percent) in *regency/city* i year t; $lnWATER_{it}$ is access to drinking water (percent) in regency/city i year t; $lnEXP_{it}$ is total regional expenditure (rupiah) in regency/city i year t; α_i is unobserved heterogeneity; γ_t is time spesific error; and ε_{it} is the error term

From equation 1 above, to address the dynamic conditions and solve the problem of Omitted Variable Bias (OVB) and endogeneity issues, this study will estimate the role of road infrastructure in food security using the Arellano Bond Generalized Method of Moments (GMM). In addition, this study will also look at the influence of road infrastructure on each aspect of the food security index to provide an overview of the relationship between those two. All variables will be used in the logarithmic transformation to minimize problems such as collinearity and heteroscedasticity in the model.

RESULTS AND DISCUSSION

The value of the Food Security Index varies significantly, with a minimum value of 7.38 and a maximum value of 93.97, as shown in Table 1. In 2018, the areas with the lowest index values were Nduga and Intan Jaya, with scores of 7.38 and 7.81, respectively. By 2021, these two regencies remained at the bottom of the food security index rankings, with Nduga still holding the lowest position at 14.89. The highest scoring area was Denpasar City, with 93.32 in 2020 and 93.97 in 2021. According to the standardization results and the scale distance (0-100) issued by the Food Security Agency (BKP), regions in Indonesia can be categorized into six food security groups. Group 1 represents the most food-insecure areas, with a lower cutoff score of 41.52 for regencies and 28.84 for cities. Conversely, Group 6 represents areas with the highest food security, with an upper limit of 75.68 for regencies and 70.64 for cities.

The distribution of food security across Indonesian islands is illustrated in Figures 2 and 3. The highest percentage of regencies with IKP values above the threshold (75.68 for regencies) is found on the island of Java, with 89.29%. At the same time, all cities on the island of Sulawesi have IKP values above the threshold (70.64 for cities), indicating a high food security status. However, the lowest percentage of regencies with IKP values above the threshold was found on Maluku Island and Papua, at just 3.51%. Similarly, only 50% of Maluku and Papua islands met the threshold among cities (70.64). This indicates that Maluku and Papua are among the most food-insecure regions in Indonesia. This finding aligns with the Food Security Agency's observation that the eastern region of Indonesia has consistently ranked lowest in the food security index from 2018 to 2021.

Most roads in stable condition are still predominantly located in the Java and Sumatra regions. Data from 2018-2021 show that these two islands account for 61% of stable roads, with Sumatra Island having 33% and Java Island 28% of the total stable roads. The remaining percentage is distributed among other islands, as illustrated in Figure 4. Figure 5 further indicates that, across these islands, the number of stable roads in Indonesia has been increasing annually, with Java and Sumatra remaining the predominant regions.

The scatter plot in Figure 5 demonstrates that the relationship between stable road infrastructure and food security is trending positively. An increase in stable roads appears to correlate with improved food security in a region. However, this effect is only observed in some regions of Indonesia.

Table 1. Summary Statistics

Variable	Obs	Unit	Mean	Std. Dev.	Min	Max
Food Security (FSI)	2.032	index	70,93	14,44	7,38	93,97
Steady Road (SROAD)	2.032	km	512,51	340,79	11,22	2.946,50
Irrigation (IRR)	2.032	ha	8.385,18	10.231,82	0	88.556,00
ADHK GDP (GDP)	2.032	trillion rupiah	18,04	31,82	0,13	410,88
Total Regional Expenditure (EXP)	2.032	billion rupiah	1.561,46	991,37	490,75	9.162,66
Education (EDU)	2.032	years	8,25	1,63	0,85	12,83
Area (AREA)	2.032	km^2	3.760,11	5.574,37	16,06	45.792,33
Total Population (POP)	2.032	thousands	505,56	580,74	23,13	5.198,69
Sanitation Access (SANIT)	2.032	%	72,40	20,62	0	100,00
Clean Water Access (WATER)	2.032	%	80,26	17,84	0	100,00

Source: Data Processed, 2023

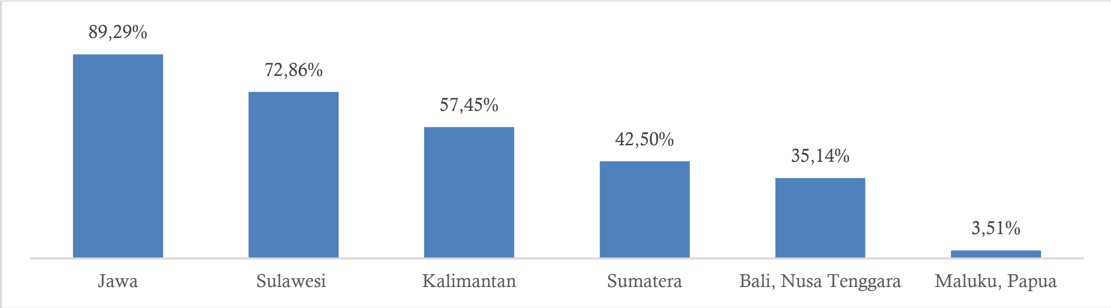


Figure 2. The Regency above the Food Security Threshold
Source: Food Security Agency, Processed, 2023
Notes: Regency Threshold 75,68

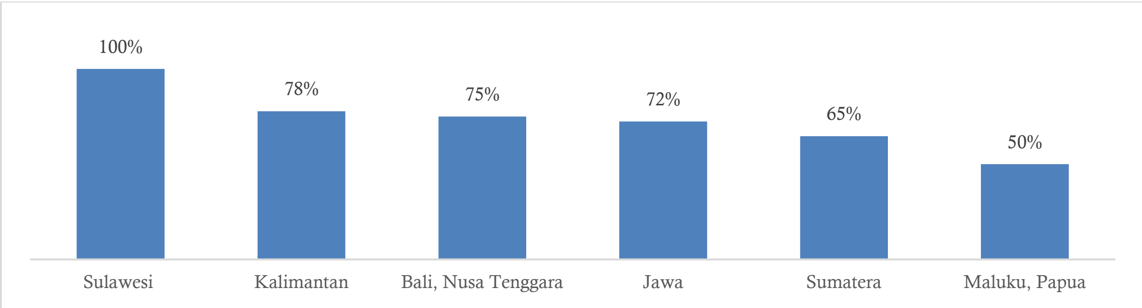


Figure 3. The City above the Food Security Threshold
Source: Food Security Agency, Processed, 2023
Notes: The City's Threshold 70,64

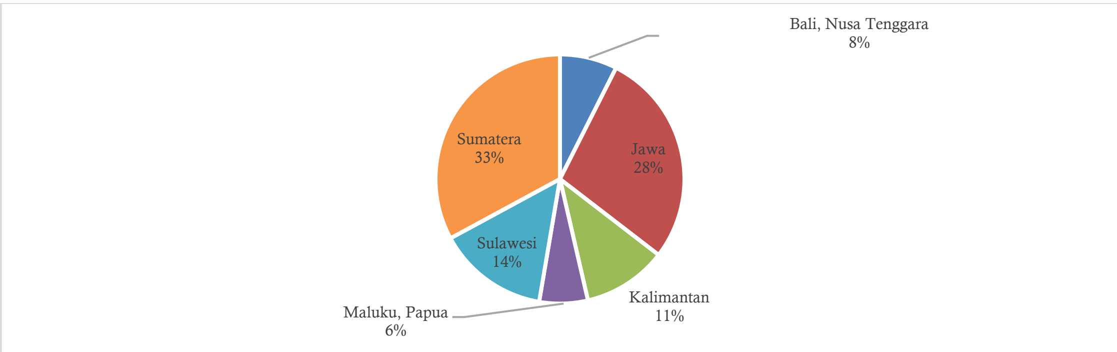


Figure 4. Distribution of Steady Roads by Island
Source: Food Security Agency, 2023 (Processed)

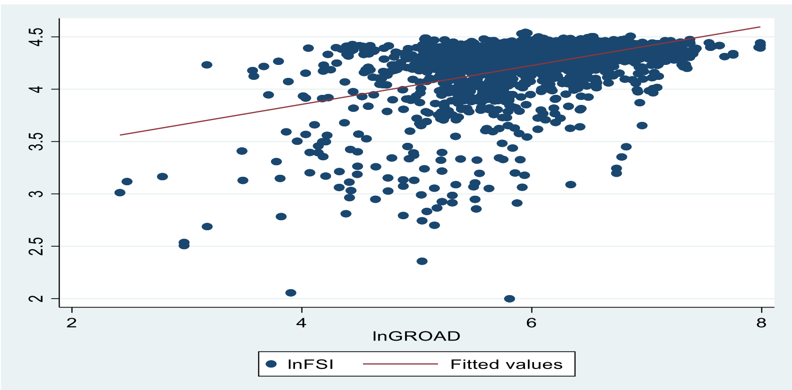


Figure 5. Scatterplot of Steady Road and Food Security
Source: Food Security Agency and Central Bureau of Statistics, Processed, 2023

Several areas have more than 800 kilometers of stable roads; however, their food security index values remain below 41.52, classified as category group 1 by the Food Security Agency, indicating the highest level of food insecurity. These areas in the Papua and West Papua provinces include Pegunungan Bintang, Mappi, and Teluk Bintuni. This situation suggests that targeted interventions are necessary to improve food security in these regions. The Food Security Agency (2021) also reported that the eastern region of Indonesia generally has a lower food security index than the western region, necessitating prioritized efforts to address food vulnerability.

Table 2 presents the estimation results using Ordinary Least Squares (OLS), which yield a lagged dependent variable parameter (L.FSI) of 0.8411, serving as the upper bound. Fixed effect estimation results show a lagged dependent variable parameter (L.FSI) of -0.0008, representing the lower bound. In contrast, the one-stage difference Generalized Method of Moments (GMM) estimation provides a lagged dependent variable parameter (L.FSI) of 0.0747. Due to methodological considerations, these values are close to or above the lower bound of -0.0008. Although Bond & Temple (2001) found that two-stage GMM results offer smaller standard errors, both single-stage and two-stage GMM methods have their characteristics. Asymptotic theory suggests that the two-stage GMM method is more efficient, but this efficiency might be more relevant for smaller samples (Hwang & Sun, 2015). The difference in efficiency between one-stage and two-stage estimators is minimal, and further testing is needed to confirm whether the two-stage estimator is superior to the single-stage one. System GMM is considered a robust estimator due to its consistency. Additionally, single-stage GMM estimators are more reliable when dealing with potentially insignificant but endogenous variables (Soto, 2009). Therefore, coupled with the results of the parameters lag lnFSI of the two-stage system GMM, which are insignificant and the standard error is larger, this research will use the one-stage system GMM as another estimation method.

In this study, the Arellano-Bond test was also performed with the single-stage GMM system at the time of estimation. The results were obtained when the first order was -4.10 and significant at a significance level of 5%. However, the second-order results of this test were not shown. This is probably due to the short observation period of only four years (2018-2021). Therefore, the results of the Arellano-Bond test in this study only accept H0 based on the results of the first-order test. This means that there is an autocorrelation problem due to the short observation time.

Table 2. Summary of Estimating the Effect of Road Infrastructure on Food Security Using the Dynamic Data Panel Method

Variables	(1)	(2)	(3)	(4)
	OLS	**FE**	**One-step Diff-GMM**	**One-step Sys-GMM**
L.lnFSI	0.8411^{***}	-0.0008	0.0747	0.5226^{***}
	(0.0244)	(0.0976)	(0.1399)	(0.1842)
lnSROAD	0.0186^{***}	0.0184	0.0194	0.0205^{**}
	(0.0065)	(0.0130)	(0.0160)	(0.0091)
lnIRR	0.0070^{***}	-0.0033	-0.0065	0.0238^{**}
	(0.0018)	(0.0091)	(0.0122)	(0.0100)
lnEXP	-0.0276^{**}	-0.0238	-0.0210	-0.0711^{**}
	(0.0122)	(0.0429)	(0.0429)	(0.0319)
lnGDP	0.0063	-0.1881^{*}	-0.1529^{*}	0.0233^{*}
	(0.0047)	(0.1072)	(0.0826)	(0.0129)
lnEDU	-0.0015	0.3872	0.3159^{*}	0.0510
	(0.0163)	(0.2574)	(0.1913)	(0.0355)

Variables	**(1)**	**(2)**	**(3)**	**(4)**
	OLS	**FE**	**One-step Diff-GMM**	**One-step Sys-GMM**
lnAREA	-0.0093***	0.0377	0.0317	-0.0124***
	(0.0023)	(0.0244)	(0.0298)	(0.0036)
lnPOP	0.0035	-0.0232	-0.0215	0.0183
	(0.0077)	(0.1025)	(0.1010)	(0.0141)
lnSANIT	0.0101	-0.0732***	-0.0735***	0.0653*
	(0.0135)	(0.0136)	(0.0125)	(0.0338)
lnWATER	0.0245*	-0.0409	-0.0396	0.0451**
	(0.0127)	(0.0274)	(0.0278)	(0.0204)
_cons	29.8219***	4.4940***		26.7204***
	(4.1798)	(1.6381)		(5.1234)
Obs	1290	1290	855	1290
R^2	0.8890	0.0818	-	-
Adj R^2	0.8881	0.0732	-	-
Number of groups	-	435	428	435
Arellano-Bond test for AR (1)	-	-	0.0394	0.0000
Hansen test	-	-	0.3402	0.1410

Notes: The Arellano Bond Test for AR (2) is not available due to short research period
Standard errors in parentheses ; $p < .1$, ** $p < .05$, *** $p < .01$
Source: Data Processed, 2023

Table 2, column 4, shows that road infrastructure positively affects food security, with a significance level of 5%. Greene (2018) identifies two types of influence an independent variable can have on a dependent variable: short-term and long-term. In the short term, a 1 percentage point increase in road infrastructure is associated with a 0.0205 percentage point increase in the food security index. However, the long-term effect is more pronounced. This is because the food security index comprises numerous indicators that interact with each other and are influenced by their values in the previous period, resulting in a unified index. This dynamic process continues to shape the food security index in subsequent periods. In the long term, the impact of road infrastructure on food security is calculated as 0.0205/(1 – 0.5226). Therefore, a 1% increase in road infrastructure results in a 0.0429% increase in the food security index, indicating that the long-term effect is approximately twice as large as the short-term effect.

These findings are consistent with Baek (2016), which suggests that public transportation can reduce food insecurity. They are also aligned with Zhou et al. (2021), who found that road construction positively and significantly influences agricultural development sustainability. Additionally, the results corroborate those of Qin et al. (2022), which indicate that road construction enhances economic growth through tertiary industries and indirectly reduces poverty through trickle-down effects from economic growth. Thus, this research supports the conclusion that road infrastructure positively affects the food security index.

Similarly, irrigation can positively and significantly impact food security at the 5% level. A 1% increase in irrigation expansion leads to a 0.0238% increase in food security in the short run. In the long run, a 1% increase in irrigation development results in a 0.0498% increase in the food security index (0.0238/(1 - 0.5226)). This effect is comparable to the impact of road infrastructure, which is more pronounced in the long run than in the short run. These findings are consistent with research by Zainuddin (2021), Gohar et al. (2015), and Bazzana et al. (2020), which indicates that irrigation development has a positive and significant effect on food security.

Although there is considerable research on the relationship between road construction and food security, examining how road construction affects each aspect of the food security index is essential. This analysis provides a more comprehensive understanding of the relationship between these variables. Therefore, this section explores the impact of road infrastructure development on food availability, affordability, and utilization.

From the estimation results using the single-stage system GMM in Table 3, road construction and irrigation generally impact food security in terms of food availability and utilization. Road construction has a positive and significant impact on food utilization at the 1% level. So, if steady road construction increases by 1%, in the short run, the food security index increases by 0.0127%. Meanwhile, the influence of road on food utilization in the long run is 0.0127/(1 - 0.7185), i.e. 0.0451%. While irrigation influences the aspects of food availability and utilization, it is insignificant.

In Table 3, the value reported for each aspect of the food security index indicates the speed of adjustment. The results obtained are delayed. lnAVA and lnAFF in columns 1 and 2 have values greater than 1 (positive and negative). This suggests that quite rapid and large changes have taken place in these two aspects. Meanwhile, the lagged value lnUTI in column 3 is between 0 and 1 and is larger than the coefficient values of roads and irrigation. It shows that the impact of roads and irrigation takes time to impact food use.

The Hansen test indicates that the model is valid, although the results of the Arellano-Bond test for AR (1) and AR (2) are not available until 2019 due to limited data periods in which data for each aspect of food security are available cannot be presented - 2021. Meanwhile, the construction of roads and irrigation has had a negative impact on food affordability. Affordability is assessed by the number of poor people, public spending, and access to electricity. According to Makmuri (2017), the existence of roads increases income inequality. This is because roads have a limited impact on household income. In Indonesia, the increase in paved roads only increases the number of private vehicle ownership among middle- to upper-income households. As private vehicle ownership increases, so do productivity opportunities. It does not apply to low-income households. They also influence being productive, although smaller than upper-middle-income households. The government should have taken measures related to the negative impact of road construction on affordability, especially poverty and income inequality, and taken appropriate measures to achieve equal food security.

These results suggest that road construction and irrigation partially positively impact food security, namely on the food availability and utilization components, as shown in Table 3. This means that constructing roads and irrigation will increase public consumption and net food production such as rice, corn, cassava, sweet potatoes and rice stocks (Nichols, 1969). Good roads move people, goods and capital from one district/city to another. Road construction results in an increase in surplus workers, including health and education workers, moving from villages to cities and increasing the productivity of the rural workforce. In addition, good roads will improve the smooth flow of resources such as medical equipment and education and ultimately increase food utilization through health and education. The development of irrigation increases the production of basic goods through the development of agricultural facilities and infrastructure in the irrigation sector. Therefore, a comprehensive policy that covers both aspects of food security is needed to increase Indonesia's food security.

Table 3. Summary of Estimating the Effect of Road Infrastructure on Food Security Aspects

Variables	**(1)**	**(2)**	**(3)**
	lnAVA	**lnAFF**	**lnUTI**
L.lnAVA	-1.4836		
	(1.7149)		
L.lnAFF		1.3670^{***}	
		(0.2662)	
L.lnUTI			0.7185^{***}
			(0.1250)
lnSROAD	0.0504	-0.0014	0.0127^{***}
	(0.0755)	(0.0066)	(0.0049)
lnIRR	0.2324	-0.0069	0.0027
	(0.1921)	(0.0059)	(0.0019)
_cons	8.1502	-1.2214	0.7093^{**}
	(5.4239)	(1.0026)	(0.2959)
Obs	673	858	858
Number of Groups	342	434	434
Hansen test	0.6015	0.9412	0.1306

Notes: The results estimated with one-step System GMM as Table 2 Column 4,
Arellano Bond Test for AR (1) and AR (2) are not available due to short research periods (2018-2021)
Standard errors in parentheses; * $p < .1$, ** $p < .05$, *** $p < .01$
Source: Data Processed, 2023

Table 4. The magnitude of the Effect of Roads and Irrigation on Food Security

Variables	**Short Run Effect**				**Long Run Effect**			
	FSI	**AVA**	**AFF**	**UTI**	**FSI**	**AVA**	**AFF**	**UTI**
Road (SROAD)	0,0205	0,0504	-0,0014	0,0127	0,0429	0,0203	0,0038	0,0451
Irrigation (IRR)	0,0238	0,2324	-0,0069	0,0027	0,0499	0,0936	0,0188	0,0096

Note: the resulting values in the table above are obtained from the formula = road or irrigation coefficient/(1 - lagged dependent variable). The dependent variables are the food security index (FSI), availability aspect (AVA), affordability aspect (AFF), and utilization aspect (UTI). The values of all coefficients are taken from Table 4.4 and Table 4.5. The Value of *lagged* dependent variables include FSI (0.5226), AVA (-14836), AFF (1.367), and UTI (0.7185).
Source: Data Processed, 2023

These results show that road construction and irrigation affect food security positively and partially, namely on food availability and utilization, as shown in Table 3. This means that constructing roads and irrigation increases public consumption and net food production, such as rice, corn, cassava, sweet potatoes, and rice stocks. With good roads, people, commodities, and capital move from one district/city to another. Road construction increases surplus labor, including health and education workers, moving from villages to cities, and increasing rural labor productivity. Apart from that, good roads will improve the smooth flow of resources such as health equipment and education, ultimately improving food utilization through health and education. Irrigation development increases the production of basic commodity commodities by developing agricultural facilities and infrastructure in the irrigation sector. For this reason, a comprehensive policy that covers both aspects of food security is needed to achieve a more secure food system in Indonesia.

All the results in Table 4 mainly conclude in terms of the magnitude of the effect in the long term, which is, on average, greater than in the short term. The construction of roads and irrigation cannot directly affect food security in the current year or the following year in which roads and irrigation are built. Thus, the effects of roads and irrigation will have a greater influence on food security in the long term, so it will take longer to produce optimal results.

To enrich the results of this research further, we will show the results of the estimated dummy from the islands of Indonesia below. Those islands are dummy Sumatera Island, dummy Java Island, dummy Kalimantan Island, dummy Nusa Tenggara and Bali Islands, dummy Sulawesi Island, and dummy Maluku and Papua Islands. By adding the control variables, year fixed effect, and all dummy Islands, the results are obtained in Table 5. In this table, there are six islands in total. The estimation results show five dummy Islands, with Sumatra Island as the basis function. For the dummy city, the estimation results show that the difference in the average food security index in city areas is 8.25% lower than that of the regency. In Table 5, the average food security index on the islands of Kalimantan and Sulawesi is higher than on the island of Sumatra. Meanwhile, the average Food Security Index on Maluku and Papua Islands is lower than on Sumatra Island. Thus, there are differences in the average food security index on the islands in Indonesia.

Based on the results from Table 5, Indonesia's average food security index on each island is significantly different than in Table 6. The research was carried out with a dynamic panel data subsample per island using the approaching island by year fixed effect and dummy city. It was done to get stronger results in seeing the differences in characteristics between islands in Indonesia and the influence of steady roads on the food security index. The dummy variable used is variables dummy city , where the variable will have a value of 1 if it is an area with city administrative status and 0 if it is an area with district administrative status. It is to see the difference in Indonesia's average food security index in urban and district areas.

In Table 6, road construction has a different influence on food security on each island. In general, it is a positive influence, although not significant. Road construction affects Maluku and Papua Islands' food security positively and significantly at the 10% significance level. When there is an increase in steady road construction of 1%, there is an increase in the food security index of 8.71%. It indicates that the construction of solid roads on the islands of Maluku and Papua will have a significant impact on increasing food security. As FSA (2018) stated, Papua has had the same problem with food security since 2018. Therefore, one of the goals of increasing food security in the eastern region of Indonesia can be realized by improving roads in good condition in the region. However, increasing the number of steady roads must still pay attention to the principles of green environmental health. It is to avoid deforestation of green land intended for road construction which can have negative consequences for forests and land, as well as the ecosystem within them.

Table 5. Estimation Results (Dummy Islands)

Variables	lnFSI
L.lnFSI	0.4563**
	(0.1948)
lnSROAD	0.0158*
	(0.0084)
lnIRR	0.0129**
	(0.0066)
Dummy City	-0.0825*
	(0.0430)
Dummy Jawa Island	0.0163
	(0.0116)
Dummy Kalimantan Island	0.0422*
	(0.0228)

Variables	lnFSI
Dummy Nusa Tenggara and Bali Island	0.0060
	(0.0109)
Dummy Sulawesi Island	0.0515***
	(0.0181)
Dummy Maluku and Papua Island	-0.0949***
	(0.0326)
_cons	1.6873***
	(0.6415)
Obs	1290
Number of_Groups	435
Arellano-Bond test for AR (1)	0.0002
Hansen Test	0.0687

Note: Estimated results use a one-step System GMM, as shown in Table 2, Column 4. Arellano-Bond method test for AR (2) does not appear due to the limited number of research periods (2018-2021)

Standard errors in parentheses;* $p < .1$, ** $p < .05$, *** $p < .01$

Source: Data Processed, 2023

Irrigation development affects food security on the islands of Sumatra, Nusa Tenggara, and Bali, where the results state that there is a positive and significant influence at the 10% significance level. When there is a steady increase in road construction of 1%, there is an increase in the food security index on the island of Sumatra by 3.39% and on the islands of Nusa Tenggara and Bali by 4.15%. These results can be recommended for further government policy that equal distribution of irrigation areas in the Nusa Tenggara Islands, Maluku, Papua, Sulawesi, and Sumatra must be considered to reduce food insecurity.

Meanwhile, the variable value dummy cities in Table 6 generally have negative values. This is consistent with the results in Table 5. In general, the average food security index difference is lower by a percentage on each island compared to the district. In the case of Indonesia, this might happen because the number of district administrative areas is greater than the number of urban administrative areas. At the beginning of the discussion, it was previously stated that in 2018-2021, there would be 415 districts and 93 cities out of 508 regions. This means that 81.7% of the territory in Indonesia is district administrative areas. Thus, if there is an increase in the number of solid roads in the district, the potential for increasing food security could also be greater. Raw materials in the form of agricultural products from areas around urban areas support industry development in urban areas. This is due to the limited amount of agricultural land in urban areas. Then, the movement of surplus labor in the agricultural sector becomes a source of economic growth. In Indonesia, Jakarta, as a barometer of economic growth, is in a strategic position regarding the economic growth of food buffer areas. Jakarta has become dependent on food sourced from domestic production, especially in the surrounding areas (Sulaiman et al., 2018).

Table 6. Estimation Results (Subsample)

Variables	(1) Sumatera	(2) Jawa	(3) Kalimantan	(4) Nusa Tenggara and Bali	(5) Sulawesi	(6) Maluku and Papua
L.lnFSI	0.1344	0.4826*	0.3653*	-0.8286	0.5049	0.6053***
	(0.3623)	(0.2669)	(0.1937)	(0.6236)	(0.3302)	(0.2120)
lnSROAD	0.0173	0.0187	0.0422	0.0111	-0.0119	0.0871*
	(0.0237)	(0.0143)	(0.0340)	(0.0369)	(0.0120)	(0.0458)
lnIRR	0.0339*	-0.0041	-0.0068	0.0415*	0.0181	0.0145
	(0.0177)	(0.0058)	(0.0146)	(0.0226)	(0.0162)	(0.0182)
Dummy City	-0.1104	-0.0927**	-0.1857**	-0.2839**	0.0148	-0.0370
	(0.1113)	(0.0441)	(0.0839)	(0.1342)	(0.0393)	(0.1315)
_cons	3.0018**	1.7799**	3.0245***	4.8065***	1.9312	1.6222
	(1.3691)	(0.8560)	(0.9728)	(1.3864)	(1.4435)	(1.0782)
Obs	399	303	153	123	214	98
Number of_Groups	134	101	51	41	72	36
Arellano-Bond test for AR (1)	0.1655	0.0175	0.0034	0.4218	0.0874	0.0019
Hansen Test	0.3609	0.9167	0.9454	0.7782	0.7446	0.7452

Note: Estimated results use a one-step System GMM, as shown in Table 2, Column 4. Arellano-Bond method test for AR (2) does not appear due to the limited number of research periods (2018-2021)

Standard errors in parentheses; * $p < .1$, ** $p < .05$, *** $p < .01$

Source: Data Processed,

CONCLUSION

The aim of this study is to examine the relationship between the availability of road infrastructure and the level of national food security in Regency and City in Indonesia. This study concludes that road infrastructure in excellent and moderate (stable) condition has a positive and significant impact on national food security in Regency and City in Indonesia, especially in the long term. In addition, the steady path also positively and significantly influences aspects of food security consisting of availability and utilization. However, the aspect of affordability will not be affected by the road construction. Thus, road infrastructure increases food security partly in terms of food security.

The government can continue to expand robust road construction and irrigation and ensure that food sources are maintained, particularly in terms of food availability and utilization. However, the government needs to pay attention to food affordability issues as these are not affected by robust road infrastructure. The indicators used in the affordability perspective are likely influenced by factors other than the variables used in this study.

Based on this research, the results show differences in the characteristics of Indonesia's average food security index per island and the influence of steady roads on food security, which is also different on each island. Increasing the number of solid roads in the Maluku and Papua islands and the amount of irrigation in the Sumatra, Nusa Tenggara, and Bali regions has increased food security significantly.

Other factors such as irrigation, GRDP, access to sanitation, and drinking water also contribute significantly to increasing food security. Therefore, a comprehensive infrastructure development policy to alleviate food insecurity should focus on roads, irrigation, sanitation, and drinking water infrastructure. Various parties, including government and society, need comprehensive, communicative, and cooperative policies to accelerate the achievement of food security in all regions of Indonesia.

To achieve equitable food distribution in Indonesia, improved sanitation and drinking water access must also be considered. This study found that both could also significantly increase food security. The widely varying access to sanitation and drinking water leads to an imbalance in food security in Indonesia. For this reason, measures to develop sanitation and drinking water infrastructure, particularly to increase food security, must be considered.

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