ORIGINAL ARTICLE

Determinants of low birthweight in Indonesia: a provincial-level ecological study

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ABSTRACT

Low birthweight (LBW; <2500 g) serves as a significant indicator of maternal and fetal health, with implications for predicting mortality, stunting, and the development of chronic conditions in adulthood. Inadequate maternal nutrition during pregnancy is a key contributing factor to LBW. However, the determinants of LBW are complex and context-specific, and evidence at the subnational level in Indonesia remains limited. This ecological study aimed to analyze the determinants of LBW in 34 provinces of Indonesia from 2019 to 2023 using panel data analysis. The results of this study indicated that the factors that significantly influenced the decline in LBW were antenatal care visits 4+ (ANC4+), antenatal care visits 6+ (ANC6+), diphtheria, tetanus, and pertussis (DTP) immunization, iron supplement consumption, supplementary feeding programs for pregnant women, health insurance, mean years of schooling, social assistance, sanitation, public health centers, hospitals, and midwives. The factors that significantly influenced the increase in LBW cases were unemployment, early marriage, smoking, and forest fires. These determinants spanned the health system and socioeconomic, environmental, and climatic domains, reflecting the multidimensional nature of LBW at the provincial level in Indonesia. Policy recommendations focus on two areas. First, health service-level interventions include strengthening health infrastructure and resources, integrating cross-sectoral LBW case surveillance data, and implementing performance-based budget allocation in priority provinces. Second, interventions should address socioeconomic and environmental determinants by improving living standards and employment opportunities, implementing conflict-of-interest tobacco control governance, and mitigating air pollution. Further ecological studies should utilize microeconomic data, analyze them quantitatively, and systematically explore them using a qualitative approach.

Keywords:
low birthweight, health, socioeconomic status, environmental, ecological study

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INTRODUCTION

Low birthweight (LBW) is a significant health concern for neonates, defined as a birthweight of less than 2500 g and this condition may result from preterm birth, occurring before 37 weeks of gestation, intrauterine growth restriction, or a combination of both factors.[1] LBW cases are found not only in developing and impoverished countries[2] but also in developed countries such as the US, UK, Canada, and Australia.[3] LBW is a significant public health problem in many countries, and various prevention programs have been implemented to reduce its incidence.

Maternal malnutrition, chronic energy deficiency (CED), and inadequate care during pregnancy are all contributing factors to LBW.[4] Babies with LBW, based on epidemiological observations, are often stillborn.[5] Stillbirths in health facilities during pregnancy are influenced by inadequate antenatal care (ANC) visits, early pregnancy, and pregnancy-related complications.[6] According to global statistics, in 2020, 19.8 million live births were born globally, 14.7% of whom were born with LBW.[7] Those born with LBW are vulnerable to health problems, low IQ, stunting, and non-communicable diseases.[8]

LBW is a significant public health challenge for pregnant women in Indonesia.[9] Limited access to health facilities, poverty, and income inequality contribute to LBW in rural areas.[10] Low parental education and wages contribute to LBW.[11] Complex, interacting, multidimensional factors significantly influence the risk of LBW.[11–13] In 2023, Statistics Indonesia recorded 147,600 LBW cases in 38 provinces.[14] The same report also stated that 84.3% of newborns were weighed, and approximately 3.9% of these babies were born with LBW.[14]

The potential for stunting is often observed in babies born with LBW.[4] This condition is caused by intrauterine growth restriction and persists until birth.[10,15] This systemic effect is reinforced by the findings of a study in Pakistan, which found that incidents of delayed psychomotor development and malnutrition trigger children's growth and developmental issues.[16] A study in Wuhan, China reported similar findings, where LBW cases disrupted gross motor development, fine motor skills, and adaptive skills in infants.[17] Various developmental disorders are caused by nutritional insufficiency, particularly energy and essential proteins.[4] Evidence from studies using data from the Indonesian family life survey 5 (IFLS5) shows that LBW occurs in pregnant women who do not attend ANC visits, have high parity, hypertension, CED, gestational complications, and low maternal education.[18] The incidence of LBW contributes to the low rate of exclusive breastfeeding. Exclusive breastfeeding significantly supports infant growth and development during the first 1,000 days of life.[4]

Household socioeconomic status is a critical factor in LBW pathogenesis.[9] Using microeconomic data at the household level in Indonesia, poverty, parental education, and smoking habits increase the likelihood of having a baby with LBW, whereas babies born with normal birthweight are found among parents with formal employment and adequate housing in urban areas.[11] A case study in Nepal reported that pregnant women with heavy physical workloads and poor nutritional intake are at an increased risk of developing LBW.[19] Using data from the 2021 national socio-economic survey (SUSENAS), it was revealed that at the provincial level, the highest prevalence of LBW in Indonesia was found in North Moluccas, and the highest number of LBW cases was found in West Java.[20] Significant factors influencing LBW in these provinces include smoking, poor nutrition, close birth spacing, and developmental disparities between rural and urban areas.[20]

Indoor air pollution generated during food preparation and inadequate housing conditions can significantly impact maternal health and the risk of LBW.[12] Air pollution significantly contributes to LBW,[21] with exposure to $PM_{2.5}$ contributing approximately 15.6% of LBW cases.[22] Pollutants such as NO_2 and O_3 have been shown to harm the health of pregnant women and their fetuses, potentially increasing the risk of LBW.[23–27] Biologically, pollutants inhaled by pregnant women can penetrate the bloodstream, disrupting placental function,[28] and triggering obstacles to transplacental oxygen and nutrient transport, which can affect fetal development.[29]

Air pollution from cigarette smoke has the potential to cause LBW. Fetuses exposed to cigarette smoke from pregnant women who smoke during pregnancy are closely linked to birth defects, premature births, and stillbirths.[30] Pregnant women who smoke have twice the risk of giving birth to a baby with a birth defect compared to non-smokers, and passive smoking increases the risk of fetal death by 23% and birth defects by 13%.[31]

Inadequate access to water, sanitation, and hygiene (WASH) is often found in households with low socioeconomic status.[32,33] This condition is often a risk factor for the health of pregnant women and their babies.[34] Using data from the 2017 Indonesia demographic and health survey (IDHS), it was revealed that inadequate sanitation, the condition of house floor materials, the age of the pregnant woman, and her education all influenced LBW.[35] Water contaminated with Salmonella and Listeria affects maternal health.[10] The incidence of Schistosoma parasitic infections is associated with adverse reproductive outcomes, including ectopic pregnancy, infertility, gestational anemia, and LBW.[4]

The health of pregnant women and their babies in Indonesia is a significant issue. We believe that an ecological study approach is not only relevant for addressing this issue but also significant for the development of social health sciences. Various factors influencing LBW cases, such as health, socioeconomic status, and the environment, in 34 provinces in Indonesia from 2019 to 2023 were examined using a panel data econometric approach. The empirical evidence from this study can be useful for policymakers to make research-based decisions regarding maternal and infant health issues. Furthermore, it can produce public policies and health development strategies as an effort to accelerate the reduction of LBW cases in Indonesia to achieve the Sustainable Development Goals (SDGs) 2030.

METHODS

Study Design

The unit of analysis in this ecological study of LBW determinants in 34 provinces in Indonesia was the population; therefore, individual variables were not examined in this study. Ecological studies are epidemiological research methods used to investigate the relationship between population-level exposure and health outcomes. Observational studies differ in their level of data analysis, focusing on groups rather than individuals.[33,36,37] Ecological studies are valuable for exploring potential relationships between factors that cannot be studied at the individual level.[33,36,37] However, ecological studies have the disadvantage of measuring at the individual level because of the lack of data related to the joint distribution of at least two or more variables within each group.[36,37]

This ecological study used a quantitative approach and panel data

analysis. According to Baltagi,[38] the use of panel data has many advantages. First, panel data are a combination of time-series and cross-sectional data, which provide more data, resulting in greater degrees of freedom. Second, combining information from time-series and cross-sectional data can address issues that arise when there are omitted variables. Panel data testing uses several modeling approaches, including the common effects model (CEM), fixed effects model (FEM), and random effects model (REM). Statistical model selection was performed to ensure efficient estimation. Two tests are used to determine the best model for the panel data: the Chow and Hausman tests.

Data Collection

The aggregate data sources used in this study of the ecological determinants of LBW in 34 provinces in Indonesia from 2019 to 2023 were secondary data obtained from publications by the Ministry of Health and Statistics Indonesia. The data are publicly accessible and have been anonymized.

Data Analysis

Data analysis was performed using Stata/MP version 17 and quantum geographic information system (QGIS) version 3.32. The data analysis steps were descriptive, spatial, model selection, and panel data analyses. This study used a comprehensive panel data method, consistent with previous research.[39] We constructed four econometric equation models, as follows:

$$LBW_{it} = \beta_0 + \beta_1 ANC4_{it} + \beta_2 ANC6_{it} + \beta_3 DTP_{it} + \beta_4 IRON_{it} + \beta_5 SUPFOOD_{it} + \beta_6 SMOKE_{it} + \beta_7 HEALTHINS_{it} + \varepsilon_{it} \quad (1)$$

In Equation 1, *LBW* indicates the number of LBW cases, *ANC4* is the coverage of antenatal care 4+ (ANC4+) services, *ANC6* is the coverage of antenatal care 6+ (ANC6+) services, *DTP* is the coverage of Diphtheria, Tetanus, and Pertussis (DTP) immunization, IRON is the coverage of iron tablet administration, *SUPFOOD* is the coverage of pregnant women experiencing CED conditions who receive additional food, *SMOKE* is the percentage of the population aged 15 years and over who smoked tobacco, *HEALTHINS* is the coverage of national health insurance program participation, *β0-β7* represent the regression model coefficients, *i* indicates the cross-section unit, *t* indicates the time series period, and *ε* indicates the residual.

$$LBW_{it} = \beta_0 + \beta_1 GRDP_{it} + \beta_2 POVERTY_{it} + \beta_3 GINI_{it} + \beta_4 UNEMP_{it} + \beta_5 MYS_{it} + \beta_6 EMR_{it} + \beta_7 SOCASSIST_{it} + \beta_8 FOODEXP_{it} + \beta_9 SANITATION_{it} + \beta_{10} WATER_{it} + \varepsilon_{it} \quad (2)$$

In Equation 2, *LBW* indicates the number of LBW cases, *GRDP* is the per capita gross regional domestic product at 2010 constant market prices, *POVERTY* is the number of poor people, GINI is income inequality, *UNEM* is the number of unemployed individuals, *MYS* is the mean years of schooling, *EMR* is the percentage of early marriage, *SOCASSIST* is the number of families receiving food social assistance benefits, *FOODEXP* is the per capita expenditure on food, *SANITATION* is the percentage of households using improved sanitation services, *WATER* is the percentage of households with access to improved drinking water sources, *β0-β10* represent the regression model coefficients, *i* indicates the cross-section unit, *t* indicates the time series period, and *ε* indicates the residual.

$$LBW_{it} = \beta_0 + \beta_1 AQI_{it} + \beta_2 WQI_{it} + \beta_3 FOREST_{it} + \varepsilon_{it} \quad (3)$$

In Equation 3, *LBW* indicates the number of LBW cases, *AQI* is the air quality index, *WQI* is the water quality index, *FOREST* is the area affected by forest and land fires (ha), *β0-β3* represent the regression model coefficients, *i* indicates the cross-section unit, *t* indicates the time series period, and *ε* indicates the residual.

$$LBW_{it} = \beta_0 + \sum_{k=1}^{7} \beta_k Health_{k,it} + \sum_{s=1}^{10} \delta_s SES_{s,it} + \sum_{e=1}^{3} \gamma_e Environment_{e,it} + \sum_{f=1}^{5} \theta_f HealthFacility_{f,it} + \sum_{c=1}^{3} k_c Climate_{c,it} + \varepsilon_{it} \quad (4)$$

In Equation 4, *HEALTH* represents seven independent variables contained in health factors, *SES* represents 10 independent variables contained in socioeconomic status factors, *ENVIRONMENT* represents three independent variables contained in environmental factors, *HEALTHFACILITY* is a control variable consisting of the number of hospitals, the number of community health centers, the number of midwives, the number of nutritionists, and the number of clinical psychologists, *CLIMATE* is a control variable consisting of the average temperature (°C), average humidity (%), and number of precipitation (mm/year), *βk*, *δs*, *γe*, *θf*, and *kc* represent the coefficients of the regression model, *i* indicates the cross-sectional unit, *t* indicates the time series period, and *ε* indicates the residual.

RESULTS

This section presents the findings of a study on the determinants of LBW in 34 provinces in Indonesia, from 2019 to 2023. Table 1 presents the descriptive statistics that provide important insights into the variables used in this study. A meaningful depiction of the central tendency is presented with a mean LBW value of 38384 and a maximum LBW value of 39739, indicating a high number of LBW cases in the study period. From 2019 to 2023, the provinces with the highest average number of cases were East Java (23610), West Java (21589), and Central Java (16471). Meanwhile, the provinces with the lowest average number of LBW cases were the provinces of West Papua (292), North Moluccas (592), and North Sulawesi (625). The low absolute numbers may reflect larger problems in the health system, namely, issues with recording and access, rather than the true state of maternal and child health. This should serve as a warning rather than an achievement.

Table 1. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
LBW	170	38384	6030	107	39739
ANC4+	170	124052	172883	3650	950398
ANC6+	170	99425	144313	2995	726161
DTP immunization	170	95862	163569	331	989742
Iron tablets	170	98394	154870	136	910811

Variable	Obs.	Mean	Std. Dev.	Min	Max
Supplementary foods	170	90.21	9.97	42.2	100
Smoked	170	10.72	1.31	4.91	13.72
Health insurance	170	75.72	9.93	53.84	99.11
GRDP per capita	170	51453	42905	12762	322619
Poverty	170	771	1069	47	4587
Income inequality	170	0.34	0.41	0.24	0.45
Unemployment	170	248215	431567	15380	2533076
Mean years of schooling	170	9.15	0.82	6.85	11.42
Early marriage	170	9.82	4.42	0.88	21.18
Social assistance	170	1598938	3914992	21013	26184572
Food expenditure per capita	170	644309	120173	429498	1055896
Sanitation	170	80.82	9.60	38.27	97.12
Drinking water	170	86.42	8.82	57.6	99.86
Air quality index	170	88.61	5.73	66.52	96.22
Water quality index	170	53.78	5.70	35.37	69.29
Forest fires	170	21977	50301	1.01	336798
Public health centers	170	298	245	44	1100
Hospitals	170	88	99	10	423
Midwives	170	9563	119811	5533	677096
Nutritionists	170	899	779	112	3887
Clinical psychologist	162	37.17	44.73	1	218
Temperature	170	27.82	1.29	23.33	38.54
Humidity	170	80.51	4.53	52.24	91.00
Precipitation	170	2728	897	490	5435

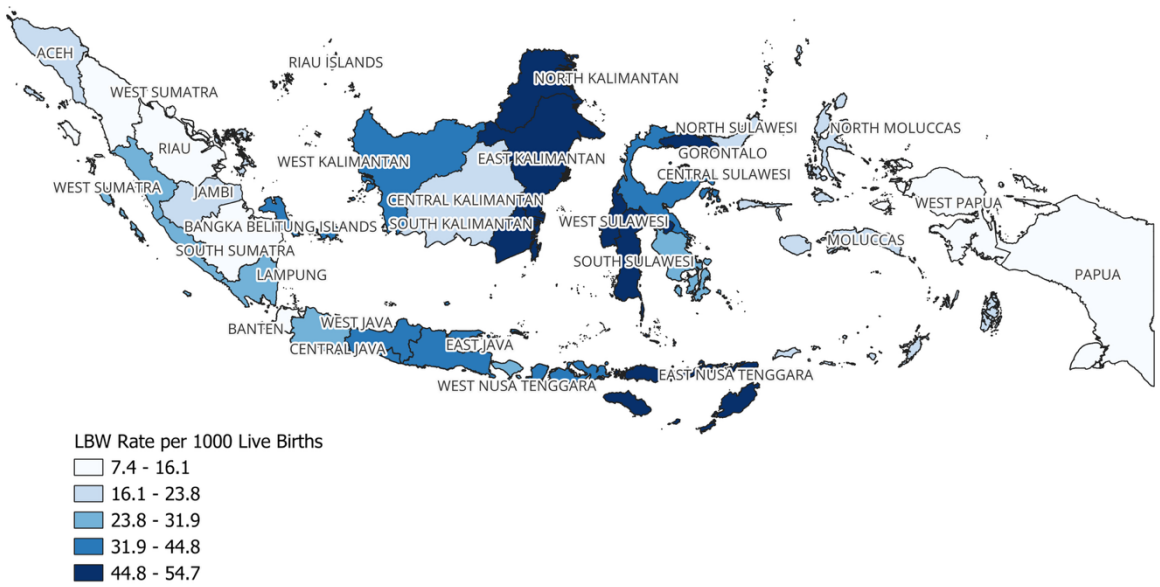


Figure 1. Average LBW Rate per 1000 Live Births in 34 Provinces in Indonesia, 2019-2023

The map visualization of the 34 provinces in Indonesia in Figure 1 shows the average LBW rate per 1000 live births from 2019 to 2023. The five provinces with the highest rates were East Kalimantan (54.68), South Kalimantan (54.11), North Kalimantan (54.01), Gorontalo (50.71), and West Sulawesi (48.88), while Riau (7.40), Jakarta (8.32), North Sumatra (8.53), South Sumatra (13.77), and Banten (14.26)

recorded the lowest rates. Geographic distribution patterns indicate that provinces in Eastern Indonesia tend to have high LBW rates. We observed a possible indirect relationship between high LBW rates in these provinces and the number of early marriages. This does not constitute direct causation, as various factors can influence the LBW rate. Furthermore, provinces with low LBW rates need to be viewed critically, as they do not necessarily reflect better maternal health conditions.

Table 2 presents the results of the model specification test. The Chow test, a cross-sectional chi-square test, was used to compare the FEM with the pooled ordinary least-squares (POLS). The Hausman test, a cross-section random-effects test, was used to compare the FEM with the REM. Both tests led to the selection of the FEM for all the model specifications.

Table 2. The Result of the Chow Test and the Hausman Test

Model	**Chow Test**		**Hausman Test**		**Conclusion**
	Stat.	Prob.	Stat.	Prob.	
1	33.129	0.0000	1.58	0.0443	FEM
2	33.126	0.0000	4.83	0.0565	FEM
3	32.124	0.0000	10.85	0.0044	FEM
4	31.93	0.0021	19.08	0.0103	FEM

The results of the panel data test using the FEM model are presented in Table 3. The estimation results of the determinants of LBW in 34 provinces in Indonesia from 2019 to 2023 were influenced by several health, socioeconomic, and environmental factors. Models 1-4 show consistent results that *ANC4+*, *ANC6+*, *DTP*, *IRON*, *SUPFOOD*, and *HEALTHINS* had significant effects on the decline in LBW cases ($p<0.05$), while the increase in LBW cases was caused by *SMOKE* ($p<0.01$). Models 2 and 4 show that socioeconomic factors, such as *UNEMP* ($p<0.01$) and *EMR* ($p<0.001$), have significant effects on the increase in LBW cases, whereas the decrease in LBW is influenced by *MYS*, *SOCASSIST*, and *SANITATION* ($p<0.01$). Models 3 and 4 show that environmental factors such as *FOREST* have a significant effect on the increase in LBW cases ($p<0.01$). The health facilities included in the Model 4, such as public health centers, hospitals, and midwives, reduced LBW ($p<0.01$).

Table 3. Panel Data Estimation Results of LBW Determinants Across Indonesian Provinces

Independent variable	Model 1	Model 2	Model 3	Model 4
ANC4+	-0.0042647*			-0.010468*
	(0.0028897)			(0.0099474)
ANC6+	-0.0094882*			-0.0070142*
	(0.0177029)			(0.0104741)
DTP immunization	-0.016233*			-0.0112836*
	(0.129127)			(0.171957)
Iron tablets	-0.0078249*			-0.0204788*
	(0.141171)			(0.0057009)
Supplementary foods	-0.0083027*			-0.0696383*
	(0.0027397)			(20.15156)
Smoked	0.0395010**			0.0746381**
	(0.0150320)			(0.0244475)
Health insurance	-0.0520850*			-0.0791870*
	(0.0572563)			(0.0724677)
GRDP per capita		0.0004383		0.0206521
		(0.0120856)		(0.129763)
Poverty		0.0873953		0.0758154
		(0.0379310)		(0.0680172)
Income inequality		0.0916763		0.0895675
		(0.0219174)		(0.1638632)
Unemployment		0.0186355**		0.0159106**
		(0.0040222)		(0.0054336)
Mean years of schooling		-0.3968255**		-0.3181539**
		(0.3170954)		(0.2650928)
Early marriage		0.0094112***		0.0074587***
		(0.1267064)		(0.8945392)
Social assistance		-0.0000913**		-0.0004601**
		(0.0000763)		(0.0001708)
Food expenditure per capita		0.004396		0.0006569
		(0.0085516)		(0.0067413)
Sanitation		-0.066695**		-0.0136108**
		(0.016776)		(0.0756798)

Independent variable	Model 1	Model 2	Model 3	Model 4
Drinking water		0.040961		50.24078
		(0.055357)		(54.244485)
Air quality index			0.036493	0.0178751
			(0.0904269)	(0.0127975)
Water quality index			0.0970852	0.0368969
			(0.0768574)	(60.35069)
Forest fires			0.0012046**	0.0038375**
			(0.0018785)	(0.0030848)
Public health centers				-0.0184098**
				(12.42293)
Hospitals				-0.02487313**
				(79.21435)
Midwives				-0.0080632**
				(0.0055494)
Nutritionists				0.745768
				(0.38657)
Clinical psychologist				0.3471927
				(0.2142549)
Temperature				0.033737
				(0.3937264)
Humidity				-0.3253945
				(0.3649819)
Precipitation				0.1805429
				(0.22888)
Constant	0.0614012**	0.3675147**	0.1879946**	0.1331846**
	(0.572363)	(0.286804)	(0.1063791)	(0.2750676)
R-squared	0.8809	0.8981	0.8733	0.9248
Number of cross-sections	34	34	34	34
Number of observations	170	170	160	152

Notes: Figures in parentheses are robust standard errors. **p<0.05, **p<0.01, and ***p<0.001*, respectively.

DISCUSSION

In the context of healthcare, ANC4+ and ANC6+ represent access to healthcare services and pregnant women's compliance with pregnancy checkups with healthcare professionals. These services include risk identification, prevention of pregnancy complications, education for pregnant women, and health promotion.[6,18,40] Routine check-ups allow healthcare professionals to comprehensively monitor the condition of pregnant women, thereby preventing pregnancy-related health problems such as LBW and neonatal mortality.[40–42]

In addition to providing protection against infectious diseases, administering DTP immunization to pregnant women can strengthen the fetus's immune system during pregnancy and at birth.[43] Pregnant women are encouraged to increase their iron (Fe) intake during pregnancy and are administered iron supplements to prevent iron-deficiency anemia, which is a factor contributing to LBW.[44] Pregnant women are advised to consume at least 90 iron supplements.[45]

Maternal nutritional status before and during pregnancy is a critical determinant of maternal health, as it affects fetal growth and development.[44,46] Pregnant women with a history of CED should receive supplemental nutrition. This has a positive impact on the likelihood of delivering a baby with normal birthweight, whereas those who do not receive supplemental nutrition are at risk of giving birth to a baby with LBW. Health insurance coverage for pregnant women is significantly associated with a decrease in LBW cases through financial protection mechanisms, increased access to quality ANC4+ and ANC6+, and facilitation of early intervention for pregnancy risks.[47]

Unborn babies exposed to cigarette smoke are highly susceptible to respiratory problems and often die from them.[4] Exposure to cigarette smoke affects the survival, health, and development of infants both before and after birth. Pregnant women who smoke can affect the health of their babies and put them at risk for birth defects, premature birth, LBW, and obesity.[10] Smoking can inhibit breast milk production because cigarette smoke contains toxins that affect fertility, pregnancy, and life expectancy.[48] Furthermore, embryonic morphological development can be delayed by smoking during the periconceptional period, from 14 weeks before conception to 10 weeks after conception.[49,50]

Households facing economic stress may have reduced material resources needed to meet basic family needs,[51] the nutritional needs of pregnant women and their fetuses,[52] and access to healthcare services.[33] Unemployed parents negatively impact children's life opportunities and reinforce intergenerational inequality.[53] This situation affects pregnant women's nutritional needs, such as receiving regular ANC4+ and ANC6+ visits, nutritional and vitamin needs, and the need for nutritious food.[11] Economic decline, as evidenced by high unemployment rates, significantly contributes to the increase in LBW cases.[54]

Highly educated couples have greater awareness and knowledge of maternal and infant health.[11,55] They heed and implement various suggestions provided by health workers during ANC visits, as they impact the health of pregnant women and their babies.[11] Mothers with higher levels of education are also more competent in making decisions, such as choosing appropriate health services and prenatal care, thus enabling them to detect pregnancy risks.[56]

Amidst the issue of reducing the national marriage rate to 7.5% by 2023, Indonesia is facing the problem of early marriage, with hundreds of thousands of children under the age of 18 marrying for various reasons.[51] Early marriage often occurs in families with a low socioeconomic status.[57] Early marriage is not a solution to economic or social issues. This practice exposes children to more

complex problems, such as high-risk teenage pregnancies, due to their physical and mental immaturity.[51] The risks faced by young pregnant women include miscarriage, anemia, bleeding, malnutrition, and maternal mortality. Risks to unborn babies include premature birth, LBW, congenital abnormalities, infection, and death.[58–60]

The social assistance received by pregnant women is a part of the family hope program (PKH). This program provides cash assistance to support maternal and child health during pregnancy and breastfeeding.[61,62] Social assistance, such as non-cash food assistance (BPNT), where beneficiary families no longer receive assistance in the form of rice but rather in the form of cash transfers.[48] Families receiving social assistance can use the money to meet the needs of pregnant women, as food needs are met through government assistance.

Household access to proper sanitation contributed to a decrease in the number of LBW cases. The percentage of households with proper sanitation needs to increase because sanitation conditions affect the health of pregnant women and their babies.[10,48] Poor sanitation is closely linked to diseases, viruses, and bacteria, putting pregnant women at risk of contracting diseases that can ultimately impact their health and that of their unborn fetuses. One such risk is the birth of a baby with LBW.[32,35]

Poor environmental impact is closely associated with critical neonatal morbidity.[63] Exposure to pollution as a health threat needs to be understood and recognized in the long term, as its impacts threaten not only the current generation, but also future generations.[64] Forest fires not only destroy forest areas but also cause air pollution that damages the health of both mothers and fetuses.[63,65] Toxic pollution from forest fires in Indonesia negatively affects the health of pregnant women and their unborn babies,[66] negatively impacting the increase in the number of LBW cases.[67]

Theoretically, several variables in Model 4 are relevant in influencing the decrease or increase in LBW; however, the results showed no statistical significance. We believe that this indicates the complexity of researching the determinants of LBW. We suspect that this insignificance was masked by other variables that showed significant effects on the decrease or increase in LBW. For example, the influence of poverty is likely masked by education, social assistance, and health insurance.

The presence of specialist health workers such as nutritionists and clinical psychologists had no significant effect on LBW. We believe that their presence is crucial in the health system. The coverage of health services, such as ANC4+ and ANC6+, is a stronger proxy for individual access to and capacity to utilize these services, and has been shown to be significant in reducing LBW. The findings of this study do not negate the importance of policies for the placement of specialist health workers and programs to address the impact of climate change. Therefore, we emphasize that investment in these factors must be accompanied by strategies to ensure equitable access and address behavioral barriers.

The findings of this study strengthen the evidence that ANC4+ and ANC6+ impact the reduction of LBW in Indonesia. However, the current global standard recommended by the WHO since 2016 has set a higher target of eight ANC visits (ANC8+).[68] In Indonesia, the provision of ANC visits from a minimum of ANC4+ [40,69] has changed to a minimum of ANC6+ since 2020,[70,71] involving prenatal check-ups by doctors in the first and third trimesters, as an effort to improve the ability to detect pregnancy and childbirth complications. Therefore, the

coverage of ANC4+ and ANC6+ remains an urgent priority in Indonesia, as it can identify the risk of pregnancy and childbirth complications. Future policies in Indonesia should design a roadmap to achieve the ANC8+ standard. This also opens a future research agenda to evaluate the feasibility and specific impact of ANC8+ in the Indonesian health system.

We acknowledge the limitations of this study, which is based on a five-year period of macroeconomic data. However, this study provides an in-depth analysis of the determinants of LBW at the provincial level in Indonesia. Future research should utilize microeconomic data, analyze it using a quantitative approach, and explore it more systematically using a qualitative approach. For example, sociocultural factors, such as domestic violence, could be considered for discussion in subsequent ecological studies.

RECOMMENDATIONS

Policy recommendations that can be implemented from a health perspective require intervention convergence by strengthening the implementation of ANC4+ and ANC6+ service standards, designing a roadmap to achieve the ANC8+ standard, ensuring universal access to iron supplementation and supplementary food for pregnant women, expanding DTP immunization coverage, and progressively strengthening tobacco control policies. Regarding socioeconomic status, strategies should focus on improving education, strengthening the effectiveness of social assistance, preventing early marriage, and strengthening workforce absorption programs. From an environmental perspective, urgent policies are needed to mitigate the impact of air pollution from forest and land fires through early warning systems and specific protection measures for pregnant women in endemic areas. All these interventions need to be supported by strengthening health infrastructure and resources, as well as integrating cross-sectoral LBW surveillance data to monitor the impact of these health development policies, with a performance-based budget allocation mechanism in provinces with high numbers of LBW infants.

AUTHOR CONTRIBUTIONS

AK: Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing-original draft, Writing-review and editing, Visualization, and Project administration.

ETHICAL CONSIDERATION

This study was approved by the Research Ethics Committee of Universitas Ngudi Waluyo, Semarang, Indonesia, with the assigned Institutional Review Board (IRB) approval (Reference Number: 342/KEP/EC/UNW/2024) on July 1, 2024.

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CONFLICTS OF INTEREST

The author declares that there are no known competing financial interests or personal relationships that could have

influenced the work reported in this manuscript.

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