DETERMINANTS OF MATERNAL MORTALITY IN INDONESIA: A B-SPLINE NONPARAMETRIC REGRESSION APPROACH TO IDENTIFY NONLINEAR RELATIONSHIP PATTERNS

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ABSTRACT
Maternal health quality is commonly assessed using the Maternal Mortality Ratio (MMR), which remains relatively high in Indonesia compared to regional and global targets. Understanding the determinants of MMR is therefore crucial for effective health policy formulation. This study aims to analyze the influence of three key factors on MMR in Indonesia: the percentage of women aged 15–49 who have ever been married and given birth to a live child, the percentage of households with access to proper sanitation, and the average years of schooling. To capture potential nonlinear relationships that may not be adequately addressed by conventional parametric regression models, this study employs a nonparametric B-spline regression approach. The analysis was conducted using the R statistical software. Model selection was based on the Generalized Cross-Validation (GCV) criterion to determine the optimal spline configuration. The results show that the optimal model achieves a minimum GCV value of 0.108 and an R² value of 0.8981, indicating a strong explanatory power and excellent model fit. The findings reveal that all three predictor variables have a significant and nonlinear effect on MMR. These results highlight the importance of considering flexible modeling approaches in maternal health studies and provide empirical evidence to support the development of more targeted and effective policies aimed at reducing maternal mortality in Indonesia.

Keywords : Maternal Mortality Ratio, B-Spline, Nonparametric Regression, Sanitation, Education, Maternal Health.

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PRELIMINARY

Maternal Mortality Ratio (MMR) is one of the key indicators in assessing a country's health development, reflecting the quality of maternal and child healthcare services as well as the socio-economic status of women. Despite various global efforts, including through the targets set in the Sustainable Development Goals (SDGs), MMR remains a serious challenge, particularly in developing countries. Numerous previous studies have highlighted various factors influencing MMR. For instance, Astuti (2021) found that access to reproductive health services and women's education levels are significantly negatively correlated with MMR. Similarly, research by Astuti (2024)

emphasized the importance of adequate sanitation infrastructure in reducing the risk of pregnancy complications that may lead to maternal death. However, most of these studies tend to analyze such factors in isolation or assume linear relationships, lacking a comprehensive view of the nonlinear interactions among demographic, environmental health, and educational indicators in a specific context.

The literature has identified various determinants of MMR, ranging from demographic to socio-economic factors. A study by Hidayat, Sumarno, and Nugrahani (2014) indicated that the proportion of women who have given birth to live children is associated with MMR, reflecting the cumulative risks posed by high parity and inadequate spacing between births. Meanwhile, Nabila, Rahmawati, and Supriyanto (2024) highlighted that access to proper sanitation significantly correlates with lower MMR, as it reduces infection risks and disease transmission. The educational dimension has also drawn attention; Tamalla and Azinar (2022) and Yoryanda and Dharmadja (2025) consistently showed that higher average years of schooling are associated with better health literacy and more informed decision-making during pregnancy and childbirth, ultimately contributing to lower maternal mortality. Nonetheless, a clear research gap remains in simultaneously and integratively analyzing the effects of the percentage of ever-married women aged 15–49 who have given birth to live children (BLC), the percentage of households with access to proper sanitation, and the average years of schooling as predictors of MMR within a single comprehensive model. Previous studies often focused on one or two variables or employed models assuming linear relationships, which may obscure more complex or nonlinear effects.

Overall, previous studies have contributed important insights by examining specific determinants of MMR, including demographic characteristics such as parity and childbirth history (Hidayat, Sumarno, and Nugrahani, 2014; Katiandagho et al., 2022), environmental health factors such as sanitation access (Nabila, Rahmawati, and Supriyanto, 2024; Astuti, 2024), and educational factors related to health literacy and maternal decision-making (Tamalla and Azinar, 2022; Yoryanda and Dharmadja, 2025). These studies generally focus on identifying the direction and strength of associations between individual predictors and MMR, thereby providing empirical evidence on how each factor independently contributes to maternal mortality outcomes.

The novelty of this study lies in its integrated and in-depth analysis of the three chosen predictor variables – the percentage of ever-married women aged 15–49 who have given birth to live children (BLC), the percentage of households with access to proper

sanitation, and average years of schooling analyzed simultaneously to predict MMR. More importantly, the study adopts a nonparametric B-spline regression approach. This methodological choice marks a significant innovation, as it allows the modeling of complex and nonlinear relationships between the predictor variables and MMR patterns that may go undetected by traditional parametric regression models, which assume linearity. This approach enables the identification of more nuanced and synergistic interaction patterns, offering a more comprehensive understanding of the factors contributing to MMR in Indonesia (Hidayat, Budiantara, Otok, and Ratnasari, 2021) (Hidayat, Ilyas, and Yuliani, 2023).

Theoretically and empirically, the relationships between the predictor variables and MMR can be explained as follows. The percentage of ever-married women aged 15–49 who have given birth to live children (BLC) is expected to have a positive correlation with MMR (Katiandagho, Setiawan, Hamonangan, and Mamahit, (2022). A higher proportion of women who have given birth, especially in the context of high parity or closely spaced pregnancies, increases the risk of complications during pregnancy and childbirth that may result in maternal death (McNestry, Killeen, Crowley and McAuliffe, 2023; Ghandali, Iravani, Habibi and Cheraghian, 2021). Each pregnancy and delivery carries inherent risks, and cumulative reproductive history may weaken maternal health. Next, the percentage of households with access to proper sanitation is expected to have a negative relationship with MMR. Poor sanitation increases the likelihood of infectious diseases (e.g., diarrhea, urinary tract infections) that can compromise the health of pregnant or postpartum women, and also indirectly affect maternal health through neonatal infections. With adequate sanitation, cleaner environments reduce infection risks, thereby supporting overall maternal well-being. Lastly, average years of schooling is also predicted to be negatively correlated with MMR (Bonacquisti, Geller and Patterson, 2020; Hartup, 2021). Higher educational attainment is often associated with better health knowledge, including awareness of nutrition, hygiene, pregnancy danger signs, the importance of prenatal care, and medically assisted childbirth (Tahira, and Fatima, 2024). Educated mothers tend to be more aware of when and how to seek medical help, adopt healthier behaviors, and make better decisions regarding reproductive and pregnancy health, which ultimately contribute to lower MMR (Adedokun and Yaya, 2020; Vikram and Vanneman, 2020).

Based on the background and research gap identified, this study has several key objectives. The first objective is to analyze the effect of the percentage of ever-married women aged 15–49 who have given birth to live children (BLC) on MMR. The second

objective is to analyze the effect of the percentage of households with access to proper sanitation on MMR. The third objective is to analyze the effect of average years of schooling on MMR. Finally, the most critical objective is to simultaneously analyze the combined effects of these three predictor variables (BLC percentage, sanitation access, and years of schooling) on MMR using a B-spline nonparametric regression approach to obtain a holistic understanding of the determinants of MMR.

This study is expected to provide several significant contributions. Theoretically, its findings will enrich the body of knowledge on MMR determinants by offering a more comprehensive and flexible model capable of capturing nonlinear relationships through the B-spline approach. Methodologically, it demonstrates the application of B-spline nonparametric regression in public health research, paving the way for similar studies facing challenges with linearity assumptions (Hidayat, Ilyas, Yuliani, Sifriani, Denysia, 2024). Practically, the results are expected to inform policymakers and health program designers in Indonesia in formulating more effective and targeted intervention strategies to reduce MMR. By thoroughly understanding how these variables interact including their nonlinear patterns resource allocation can be made more efficiently and precisely, ultimately improving maternal and child health outcomes in Indonesia.

METHODS

This study will analyze maternal mortality ratio (MMR) data in Indonesia using the B-spline nonparametric regression method. The modeling process to identify the contributing factors of MMR in Indonesia using B-spline nonparametric regression will involve several stages. First, a descriptive analysis of the research data will be conducted. This is followed by data transformation through rescaling to standardize the variable scales. Next, scatterplots will be generated for each predictor variable and the response variable to explore data patterns. The subsequent step involves determining the optimal order and knot points based on the minimum Generalized Cross-Validation (GCV) value from the rescaled data (Hidayat, Budiantara, Otok, and Ratnasari, 2019; Islamiyati, Raupong, Kalondeng, and Sari, 2022; Denysia and Hidayat, 2023). Finally, B-spline nonparametric regression modeling will be performed using the optimal order and knot points obtained from the minimum GCV value. The accuracy of the B-spline nonparametric regression model in capturing the MMR pattern in Indonesia will be evaluated using the coefficient of determination (R^2).

Mathematically, the B-spline nonparametric regression model used in this study can be expressed as:

$$y_i = \beta_0 + \sum_{j=1}^{p} f_j\left(x_{ij}\right) + \varepsilon_i \tag{1}$$

where y_i denotes the maternal mortality ratio (MMR), x_{ij} represents the j-th predictor variable, f_j is an unknown smooth function approximated using B-spline basis functions, β_0 is the intercept, and ε_i is the random error term assumed to have mean zero and constant variance.

Each smooth function $f_j\left(x_{ij}\right)$ is approximated as:

$$f_j\left(x_{ij}\right) = \sum_{k=1}^{K_j} \beta_{jk} B_{jk}\left(x_{ij}\right) \tag{2}$$

where $B_{jk}\left(x_{ij}\right)$ denotes the B-spline basis functions of a specified order with predetermined knot points, β_{jk} are the spline coefficients to be estimated, and K_j is the number of basis functions for the j-th predictor. The optimal order and knot configuration are selected by minimizing the Generalized Cross-Validation (GCV) criterion.

To clearly illustrate the research procedure, the stages of this study can be summarized in a flowchart consisting of the following steps:
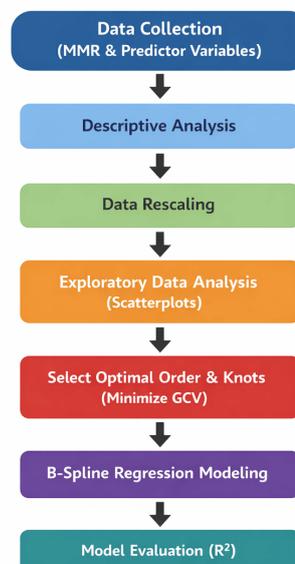

Figure 1. Flowchart of Research

The data analysis in this study employs nonparametric regression techniques with a B-spline approach. Descriptive statistics are used to summarize the characteristics of the data, followed by exploratory analysis using scatterplots to detect possible nonlinear patterns. The selection of spline order and knot points is conducted using the GCV criterion to obtain the most optimal model. Parameter estimation is then performed using least squares estimation on the selected B-spline basis functions. All statistical analyses and modeling procedures are implemented using the R statistical software, which provides flexibility and reliability for nonparametric regression analysis.

RESULT AND DISCUSSION

Before proceeding with further analysis, the initial step undertaken is to provide a general overview of the data used in this study. Descriptive statistics are presented to offer information regarding the distribution, central tendency, and variability of each of the key variables examined. These variables include the maternal mortality ratio per province, the average years of schooling, the percentage of households with access to proper sanitation, and the percentage of women of reproductive age who have given birth to live children. The presentation of descriptive statistics aims to understand the basic characteristics of the data, identify inter-regional disparities, and serve as a foundation for deeper interpretation and conclusions in the subsequent stages of analysis.

Table 1. Descriptive

	AKI	x_1	x_2	x_3
Min	48	5,1	12,61	47,41
Max	565	11,490	96,83	100
Mean	213,8	9,292	81,14	87,79

Maternal mortality in Indonesia exhibits considerable variation across provinces, with the highest number of cases reaching 565 and the lowest at 48. The national average of 213.8 cases indicates that most provinces continue to face serious challenges in maternal healthcare services, particularly in ensuring safe pregnancy and childbirth. This wide disparity suggests significant inequality in access to and quality of maternal health services across regions.

The average years of schooling also reflect educational disparities among provinces, with the highest figure at 11.49 years and the lowest at 5.1 years. The national average of 9.292 years implies that, on average, Indonesians complete education up to the junior secondary school level. Provinces with lower average schooling years are likely

facing challenges in educational access, which may be due to infrastructural limitations or socioeconomic constraints.

Meanwhile, household access to improved sanitation shows a relatively high national achievement, with an average of 81.14%. Nevertheless, some provinces report access as low as 12.61%, indicating the existence of areas still lacking basic infrastructure. In contrast, the best-performing provinces have nearly universal access, with figures as high as 96.83%, highlighting disparities in sanitation development.

The proportion of women of reproductive age (15–49 years) who have ever been married and have given birth to a live child is also high nationally, with an average of 87.79%. While some provinces report a maximum of 100%, others show figures as low as 47.41%. These differences may reflect variations in marriage practices, fertility patterns, as well as access to reproductive health and family planning services across regions.

The relationship patterns between the response variable and each predictor variable can be observed through scatterplots. The following section presents scatterplots for each predictor variable against the response variable:
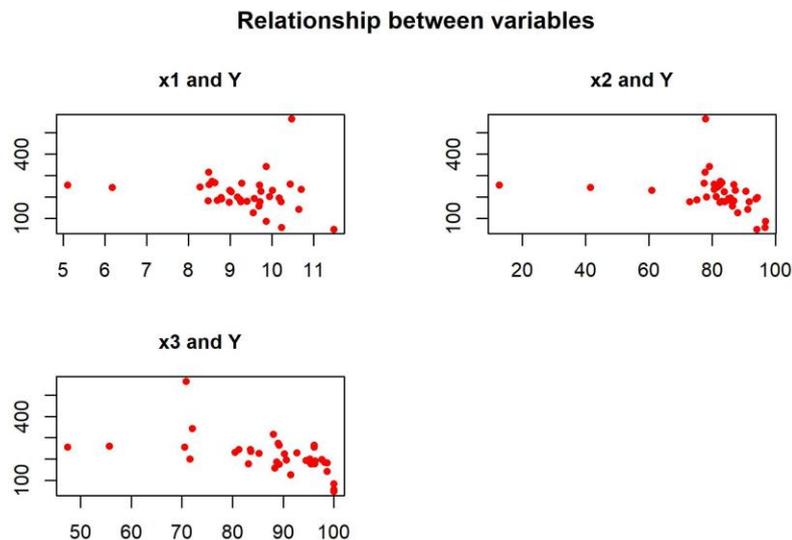

Figure 2. Scatter Plot of The Relationship Between Variables

Observations from Figure 1 indicate that there is no clear or definitive relationship pattern between the response variable and the predictors. This condition supports the application of a nonparametric regression model.

Selection of Optimal Order and Knot Locations

To identify the optimal B-spline nonparametric regression model, this study focuses on selecting the appropriate order and number of knots. We consider spline orders 2, 3, and 4, with one knot. The primary criterion for determining the best B-spline model is

the selection of the optimal knot position. This knot is chosen based on the lowest Generalized Cross-Validation (GCV) value, as a lower GCV indicates a better-fitting B-spline regression model. The results of the optimal order and knot determination based on the minimum GCV value are presented in Table 2.

Table 2. GCV Values Based on Spline Order and Knot Position

Orde			Knot			GCV
x_1	x_2	x_3	x_1	x_2	x_3	
2	2	2	9,744	84,085	86,350	0,647
2	2	3	9,277	78,959	77,915	0,283
2	2	4	9,977	84,570	88,679	0,816
2	3	2	10,787	87,025	74,710	0,195
2	3	3	9,000	87,774	85,756	0,442
2	3	4	10,688	80,823	93,091	0,891
2	4	2	10,307	88,119	82,516	0,512
2	4	3	10,527	70,730	94,470	0,552
2	4	4	10,269	81,756	79,503	0,108*
3	2	2	9,931	71,221	81,263	0,818
3	2	3	8,379	88,786	76,546	0,431
3	2	4	8,035	85,938	91,046	0,506
3	3	2	9,741	74,592	90,982	0,985
3	3	3	8,494	70,833	83,067	0,593
3	3	4	9,621	88,734	89,675	0,606
3	4	2	9,738	75,247	91,445	0,555
3	4	3	10,856	85,417	90,917	0,559
3	4	4	8,798	86,697	75,183	0,654
3	2	2	9,339	84,215	92,190	0,270
4	2	3	8,850	86,241	76,621	0,393
4	2	4	8,881	80,093	94,821	0,587
4	3	2	10,206	85,650	83,076	0,403
4	3	3	10,471	75,597	75,905	0,646
4	3	4	10,111	79,671	73,459	0,566
4	4	2	8,293	88,155	87,802	0,666
4	4	3	10,194	81,752	92,266	0,835
4	4	4	10,292	73,769	74,952	0,256

Based on Table 2, it can be concluded that the most accurate B-spline model is obtained with a minimum GCV value of 0.108. The optimal model configuration involves variable x_1 with order 2, and variables x_2 and x_3 with order 4, respectively. The optimal knot points are identified at 10.269 for x_1, 81.756 for x_2, and 79.503 for x_3.

B-Spline Nonparametric Regression Modeling

After identifying the optimal order and knot points based on the minimum GCV value, we proceed to model the B-spline nonparametric regression which yields the following equation:

$$\hat{y}_i = \beta_{11}B_{-1,2}(x_1) + \beta_{12}B_{-0,2}(x_1) + \beta_{13}B_{1,2}(x_1) + \beta_{21}B_{-3,4}(x_2) + \beta_{22}B_{-2,4}(x_2)$$
$$\beta_{23}B_{-1,4}(x_2) + \beta_{24}B_{0,4}(x_2) + \beta_{25}B_{1,4}(x_2) + \beta_{31}B_{-3,4}(x_3) + \beta_{32}B_{-2,4}(x_3)$$
$$\beta_{33}B_{-1,4}(x_3) + \beta_{34}B_{0,4}(x_3) + \beta_{35}B_{1,4}(x_3)$$

(3)

Table 3. The parameter estimation results

Variable	Parameter	Parameter Estimation
x_1	β_{11}	0,132
	β_{12}	0,167
	β_{13}	0,871
x_2	β_{21}	-0,001
	β_{22}	0,212
	β_{23}	-0,431
	β_{24}	0,651
	β_{25}	0,019
x_3	β_{31}	-0,002
	β_{32}	0,471
	β_{33}	-0,351
	β_{34}	0,691
	β_{35}	0,463

Mathematically, the results from the table above are represented by the following equation:

$$\hat{y}_i = 0,132B_{-1,2}(x_1) + 0,167B_{-0,2}(x_1) + 0,871B_{1,2}(x_1) - 0,001B_{-3,4}(x_2)$$
$$+ 0,212B_{-2,4}(x_2) -$$
$$0,431B_{-1,4}(x_2) + 0,651B_{0,4}(x_2) + 0,019B_{1,4}(x_2) - 0,002B_{-3,4}(x_3) + 0,471B_{-2,4}(x_3)$$
$$-0,351B_{-1,4}(x_3) + 0,691B_{0,4}(x_3) + 0,463B_{1,4}(x_3)$$

(4)

$$B_{-1,2}(x_1) = \begin{cases} \dfrac{5,1 - x_1}{5,1}, & 0 < x_1 \le 5,1 \\ 0, & lainnya \end{cases}$$

$$B_{0,2}(x_1) = \begin{cases} \dfrac{x_1}{5,1}, jika\ 0 < x_1 < 5,1 \\ \dfrac{1-x_1}{11,49}, jika\ 5,1 < x_1 < 1 \\ \quad 0, lainnya \end{cases}$$

$$B_{1,2}(x_1) = \begin{cases} \dfrac{x_1 - 5,1}{11,49}, jika\ 5,1 < x_1 < 1 \\ \quad 0, lainnya \end{cases}$$

Accuracy of the B-Spline Nonparametric Regression Model

To assess the accuracy of the model, this study applies the coefficient of determination, or R-squared (R^2). This indicator serves to show the extent to which the variation in the response variable can be explained by the predictor variables in a regression model. According to the principle of R-squared, values closer to 1 indicate a better fit between the model and the data. In the context of this study, the obtained R-squared value is 0.8981. Referring to Table 2.1, this value indicates a very strong relationship among the variables in the model. This implies a good fit between the observed data and the optimal B-spline model. The high R-squared value suggests that the response variable is very well explained by the predictor variables in the model.

Discussion

The optimal B-spline nonparametric regression model was obtained with order $x_1 = 2$, $x_2 = 2$, and $x_3 = 4$, and the lowest GCV value of 0.108. The coefficient of determination (R^2) value of 0.8981 indicates that the model performs very well in explaining the variation in maternal mortality (MMR) based on the predictor variables used. The strength of the relationship among variables is considered very strong, confirming the goodness-of-fit between the observed data and the resulting B-spline model. This suggests that the three predictor variables collectively have a significant influence and can predict variations in MMR in Indonesia with high accuracy.

In the B-spline model, the variable BLC (percentage of women aged 15–49 who have given birth to live children) has an order of 2 and positive estimated parameter coefficients (0.132, 0.167, 0.871). Theoretically, this variable is expected to have a positive correlation with MMR. This result is consistent with the initial hypothesis, which suggests that a higher proportion of women who have given birth especially in the context of high parity or closely spaced pregnancies increases the risk of pregnancy and childbirth complications that may lead to maternal death. Each pregnancy and delivery carries inherent risks, and the cumulative effect of multiple births may deteriorate maternal health.

This finding is in line with Hidayat and Rahayu (2021), who demonstrated a relationship between the proportion of women who have given birth to live children and MMR, reflecting the cumulative risks associated with high parity and insufficient birth spacing.

The variable representing access to improved sanitation in the model has an order of 4 with parameter estimates that vary, including both positive and negative values (-0.001, 0.212, -0.431, 0.651, 0.019). Theoretically, this variable is expected to have a negative relationship with MMR. The varying coefficients and the nonlinear pattern captured by the B-spline model indicate that this relationship may not be straightforward. The nonlinear pattern could reflect threshold effects or complex interactions. Poor sanitation increases the risk of infectious diseases, which can worsen the health of pregnant or postpartum women. However, at certain levels, further increases in sanitation access may produce different marginal effects or even a plateau effect. This finding supports the study by Wulandari (2018), which emphasized that access to improved sanitation is significantly correlated with lower MMR due to the preventable nature of many infections through proper sanitation.

The variable for average years of schooling also has an order of 4 with varying parameter estimates (-0.002, 0.471, -0.351, 0.691, 0.463). Theoretically, this variable is predicted to have a negative relationship with MMR. This result aligns with existing literature, which suggests that higher levels of education are often associated with better health knowledge, including awareness of nutrition, hygiene, pregnancy danger signs, the importance of regular prenatal checkups, and medically assisted deliveries. Women with higher education levels are generally more aware of when to seek medical care and more likely to adopt healthy behaviors. The nonlinear pattern observed for this variable may suggest that the impact of education on reducing MMR is not constant across all education levels; instead, the effects may differ at various stages of education for example, a greater impact may emerge once women attain secondary or higher education levels. This finding is supported by Anwar and Lestari (2022), whose research consistently showed that increased average years of schooling are associated with better health understanding and decision-making during pregnancy and childbirth, ultimately contributing to the reduction of maternal mortality.

Implications of the B-Spline Nonparametric Regression Approach

The application of B-spline nonparametric regression represents a significant novelty in this study. This approach has proven effective in capturing complex and nonlinear relationships between the predictor variables and the Maternal Mortality Rate

(MMR), which may not be detected by traditional parametric regression models that assume linear relationships. This is reflected in the scatterplots, which do not exhibit clear linear patterns, thus justifying the use of a nonparametric regression method. The flexibility of B-spline allows for more nuanced and synergistic identification of the relationships among variables, providing a more comprehensive understanding of the factors contributing to maternal mortality.

Policy Contributions and Implications

Practically, the findings of this study are highly relevant to policymakers and health program planners in Indonesia. By gaining a deeper understanding of how the percentage of women who have given birth (BLC), access to proper sanitation, and average years of schooling interact with MMR including their nonlinear patterns resource allocation can be more efficient and well-targeted. For instance, health education programs for women, particularly concerning pregnancy spacing and contraceptive use, become crucial. Moreover, investments in proper sanitation infrastructure must continue, considering their potentially greater impact in areas with very low access levels. Efforts to increase average years of schooling should also be prioritized, as education has been shown to improve maternal health awareness and behaviors, ultimately contributing to a reduction in MMR.

CONCLUSION

This study analyzed the determinants of the Maternal Mortality Rate (MMR) in Indonesia, focusing on the Percentage of Ever-Married Women Aged 15–49 Who Have Given Birth (BLC), the Percentage of Households with Access to Proper Sanitation, and the Average Years of Schooling, using a B-spline nonparametric regression approach. This method enables the identification of complex and nonlinear relationships between predictor variables and MMR, thereby addressing the limitations of traditional linear models.

The results show that all three predictor variables simultaneously have a strong and significant influence on maternal mortality in Indonesia. The coefficient of determination (R^2) of 0.8981 indicates that the constructed B-spline model explains the variation in MMR very well. These findings confirm that demographic factors (BLC), environmental health (sanitation), and education (average years of schooling) are key determinants of MMR.

The use of B-spline nonparametric regression has proven effective in capturing nonlinear patterns and offers a more comprehensive understanding of the dynamics underlying maternal mortality determinants. These findings are highly valuable for policymakers in formulating more targeted and efficient intervention strategies to reduce

MMR in Indonesia, considering the specific characteristics and interactions of each variable.

This study utilized cross-sectional data. Future research using panel or longitudinal data will allow researchers to observe changes in MMR over time and to analyze the dynamics of the relationship between predictors and the response variable, thereby enabling stronger identification of causal effects..

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