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Estimating Median Growth of Toddlers in Sub-District Kertosari of Banyuwangi City Based on Weight, Height and BMI Using Spline Estimator

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Abstract: *The paper describes a flexible estimating method of median growth of toddlers in Sub-District Kertosari of Banyuwangi city, a city in East Java Province, Indonesia based on weight, height, and body mass index (BMI) using a spline estimator namely least square spline. A nutritional status of toddlers characterized by a lack of weight , height, and BMI based on anthropometric indexes weight-for-age (W/A), height-for-age (H/A) and BMI-for-age (BMI/A)is called as underweight. Indonesia ranked fifth in the world in terms of malnutrition or about 3.8% of 87 millions of total Indonesian toddlers. Nationally, East Java Province is in the second position for cases of malnutrition in children under five after East Nusa Tenggara Province. In this paper we proposed the flexible estimating method of toddlers median growth using spline estimator based on generalized cross validation (GCV) criterion. The results show that the toddlers growth charts of W/A and H/A for both boys and girls of toddlers in Kertosari aged less than 6 months and aged more than 6 months tend to have an uptrend. Meanwhile, the toddlers growth charts of BMI/A for both boys and girls of toddlers in Kertosari aged more than 6 months tend to have a downward trend. In addition, the results can be used for assessing nutritional status of toddlers in Sub-District Kertosari of Banyuwangi city.*

Keywords—toddler median growth, weight, height, BMI, spline estimator.

1. INTRODUCTION

A nutritional status of toddlers characterized by a lack of weight, height, and BMI based on anthropometric indexes weight-for-age (W/A), height-for-age (H/A) and BMI-for-age (BMI/A) is called as underweight. Indonesia ranked fifth in the world in terms of malnutrition or about 3.8% of 87 millions of total Indonesian toddlers. Nationally, East Java Province is in the second position for cases of malnutrition in children under five after East Nusa Tenggara Province. According to Health Department of East Java Province, there had been an increase in cases of malnutrition by 31.36% from 4.716 cases to 6.195 cases in 2017 [1].

A Towards Health Card (in Indonesia it is called as "*Kartu Menuju Sehat* or KMS") is an instrument containing normal growth curves for toddlers based on the anthropometric index W/A. At present, Indonesia uses KMS based on WHO-2005 anthropometric standards. The use of KMS in Indonesia is based on the Z-Score curves for medians of W/A, H/A, and BMI/A. The WHO-2005 standard growth chart (SGC) takes samples of toddlers aged 0-60 months originating from Brazil, Ghana, India, Norway, Oman, and the United States. These samples are considered to represent regions of the world that are recommended as an assessment of global nutritional status [2]. However, there are different characteristics that make a difference in chart patterns from the WHO-2005 SGC, including Indonesia. Therefore, an effort that can be done to overcome the discrepancy is to design a KMS chart locally using data on children under five whose physical condition is in accordance with toddlers in Indonesia. Growth charts for toddlers every age show different patterns at each stage [3]. The pattern does not form a linear curve or a particular shape so the appropriate approach is nonparametric regression. There are several smoothing techniques in nonparametric regression, for example local linear estimators [4–6], local polynomial estimator [7], splines and kernel estimators [8–14], and one of which is the least square spline estimator with the advantage of being able to overcome data patterns that show a sharp rise or fall with the help of knots, and the resulting curve is relatively smooth [15].

Various studies on designing charts of toddler growth standards locally carried out by [16] in Padang City, but the underweight samples in this study were not differentiated by sex. Researches by [4–6] have differentiated the sex of toddlers and found that the results of the toddler growth chart design curve in East Java were lower than the WHO-2005 standard using local linear estimators. The growth standard graph was designed using percentile values for example median values. In addition to the median value, a standard toddler growth chart can be designed based on the Z-Score. The advantage of using the Z-Score based on median values is that the calculation results are more accurate and can be compared for each age group and the anthropometric index because the assessment is based on standard deviation values. Hence, calculations by using the Z-Score for median of W/A, H/A, and BMI/A can indicate the problem of malnutrition which is more optimal compared to conventional systems [17].

In designing a standard growth chart according to weight-for-age (W/A), height-for-age (H/A) and BMI-for-age (BMI/A) for toddlers with a nonparametric regression approach, there are four variables used, namely toddler weight, toddler height, toddler BMI , and toddler age for each sex. Also, we can design standard growth chart for toddlers use semiparametric regression approach. The use of the semiparametric regression approach was also carried out by [18,19] to design a standard growth chart for children under five in East Java as a determinant of wasting nutrition status based on the least square spline estimator. The growth of toddlers who are different each age will be appropriate if

approached with nonparametric regression, while the toddler sex variable is a parametric component as a dummy variable.

Based on the description above, we are interested in conducting research to estimate median growth of toddlers in sub-district Kertosari of Banyuwangi city based on W/A, H/A, and BMI/A using least square spline estimator of nonparametric regression model.

2. Material and Methods

In this section, we provide brief overview of all material and methods we used, i.e., spline estimator of nonparametric regression, generalized cross validation, coefficient of determination, and data of toddlers.

2.1 Spline Estimator of Nonparametric Regression

Polynomial pieces play an important role in approximation and statistical theory. Polynomial pieces are flexible and effective in handling the local properties of a function or data [7-13], [20], [21]. One important type of polynomial piece is spline polynomial. Spline used as approach to analyze data firstly was introduced by Whittaker in 1923, while the spline used as approach to take solution of an optimization problem was developed by Reinch in 1967 [22], [23].

Spline is one of the estimators of nonparametric regression. Spline estimator has good ability to estimate functions of data that have different behaviour in different sub-intervals. These functions that have different behavior in every sub-intervals are connected to each other by points called knots to form a spline [3], [7–26]. In general, the function $g(x)$ in spline space that has order p with knots $K_1, K_2, \dots, K_m$ is any function that can be expressed as the following equation [13], [22], [23]:

$$g(x) = \sum_{j=0}^{p} \beta_j x^j + \sum_{j=1}^{m} \beta_{j+p} (x - K_j)_+^p \quad (1)$$

where $(x - K_{j-p})_+^p = \begin{cases} (x - K_{j-p})^p, & x \geq K_{j-p} \\ 0, & x < K_{j-p} \end{cases}$

Next, if given $\lambda = (K_1, K_2, \dots, K_m)$ is smoothing parameter represented by knots $K_1, K_2, \dots, K_m$ and $\beta_j,\ j = 0,1,2, \dots, p$ are the parameters of the model given in (1) and p is the order of spline, then estimation of parameter $\beta_j,\ j = 0,1,2, \dots, p$ can be obtained by using least square method [22], [23]. In this step gives estimated parameters as follows:

$$\widehat{\boldsymbol{\beta}} = (\mathrm{X}_\lambda^T \mathrm{X}_\lambda)^{-1} \mathrm{X}_\lambda^T \boldsymbol{y} \quad (2)$$

Based on equation (2), we get estimation of function $g(x)$ in equation (1) which is expressed as:

$$\hat{g}_\lambda(x) = \mathrm{H}(\lambda)\mathbf{y} \quad (3)$$

where $\mathrm{H}(\lambda) = \mathrm{X}_\lambda (\mathrm{X}_\lambda^T \mathrm{X}_\lambda)^{-1} \mathrm{X}_\lambda^T$. Furthermore, $\hat{g}_\lambda(x)$ given in (3) is called as least square spline estimator.

2.2 Generalized Cross Validation (GCV)

In nonparametric regression one of the criteria that is used to determine the optimal knots is GCV. We can determine the best estimated MAP model by using GCV criterion that is minimum value of GCV. The GCV function which is used in nonparametric regression based on spline (i.e., least square spline) estimator is as follows [13], [22], [23]:

$$\mathrm{GCV}(\lambda) = \frac{\mathrm{MSE}(\lambda)}{(n^{-1} tr[\mathrm{I} - \mathrm{H}(\lambda)])^2} \quad (4)$$

where $\mathrm{MSE}(\lambda) = n^{-1} \sum_{i=1}^{n} (y_i - \hat{g}(x_i))^2$. (5)

Minimum value of GCV function given in equation (4) is used as a criterion for get optimal knots.

2.3 Coefficient of Determination

The coefficient of determination or R^2 stated measure of the accuracy of the regression curve [12, 13]. The purpose of calculating the R^2 value is to find out the variation of the response variable (y) that can be explained by the predictor variable (x) together. The coefficient of determination can be calculated by the following formula:

$$\mathrm{R}^2 = \frac{\mathrm{SSR}}{\mathrm{SST}} = 1 - \frac{\mathrm{SSE}}{\sum_{i=1}^{n} (y_i - \bar{y})^2} \quad (6)$$

where $\mathrm{SSE} = \sum_{i=1}^{n} (y_i - \hat{f}(t_i))^2$ and $0 \leq \mathrm{R}^2 \leq 1$.

2.4 Data of Toddlers

The data used in this study are secondary data on weight, height, BMI, and gender of children aged 0–60 months in sub-district of Kertosari, District of Banyuwangi, Banyuwangi city, East Java Province, Indonesia. Data collection was conducted in 2020 at Community Health Centers (PUSKESMAS) of Kertosari. The data obtained in the form of cross-sectional data amounted to 1,351 observations consisting of 660 observations for under five boys and 691 observations for under five girls.

3. Results and Discussion

In this section we describe results and discussion of estimating median growth of girls and boys toddlers.

3.1 Estimating Median Growth of Girl Toddlers

The estimating median growth of girl toddlers consist of estimating median growth of girls based on W/A, H/A, and BMI/A.

Estimating Median Growth of Girls Based on W/A

To obtain estimating result of median growth of girl toddlers based on weight-for-age (W/A) using spline estimator, we apply equations (1) – (6) to the data of toddlers. The results give two knots namely 6 and 36, $\widehat{\boldsymbol{\beta}} = (4.367343, 0.5120831, -0.3355113, -0.04784863)^T$, minimum GCV value of 3.155164, MSE value of 3.118635, and coefficient of determination (R^2) of 0.7164049.

Hence, we have the estimated order one spline model of median growth of girl toddlers for W/A as follows:

$$\hat{y} = 4.37 + 0.51x - 0.34(x - 6)_+ - 0.05(x - 36)_+ \quad (7)$$

So, we get the estimated spline model for W/A median growth of girl toddlers as follows:

$$\hat{y} = \begin{cases} 4.37 + 0.51x\ ; x < 6 \\ 6.41 + 0.17x\ ; 6 \leq x < 36 \\ 8.21 + 0.12x\ ; x \geq 36 \end{cases} \quad (8)$$

Next, plot of the estimated spline model for W/A median growth of girl toddlers is given in Figure 1.

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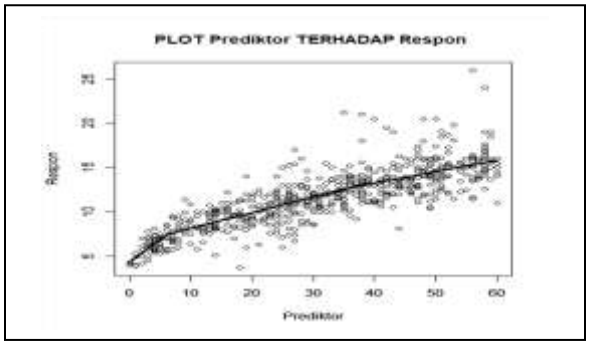

Figure 1. Plot of W/A median growth of girl toddlers.

Figure 1 shows that weight of girl toddlers aged less than 6 months and $6\text{ months} \leq \text{aged} < 36\text{ months}$ tend to have sharply uptrend, and then weight of girl toddlers aged ≥ 36 months tend to have softly uptrend.

Estimating Median Growth of Girls Based on H/A

Similarly, by applying equations (1) – (6) on the data of H/A girl toddlers, we obtain order one spline, two knots namely 6 and 36, minimum GCV value of 32.78374, MSE = 32.40419, coefficient of determination (R^2) of 0.8267132 and $\widehat{\boldsymbol{\beta}} = (53.74832\,, 2.244012\ , -1.496245\ , -0.113306\ )^T$.

Hence, we have the estimated order one spline model of median growth of girl toddlers for H/A as follows:

$$\hat{y} = 53.75 + 2.24x - 1.5(x-6)_+ - 0.11(x-36)_+ \quad (9)$$

We can express equation (9) as follows:

$$\hat{y} = \begin{cases} 53.75 + 2.24x\ ; x < 6 \\ 72.75 + 0.74x\ ; 6 \leq x < 36 \\ 76.71 + 0.63x\ ; x \geq 36 \end{cases} \quad (10)$$

So, plot of the estimated spline model for H/A median growth of girl toddlers is given in Figure 2.

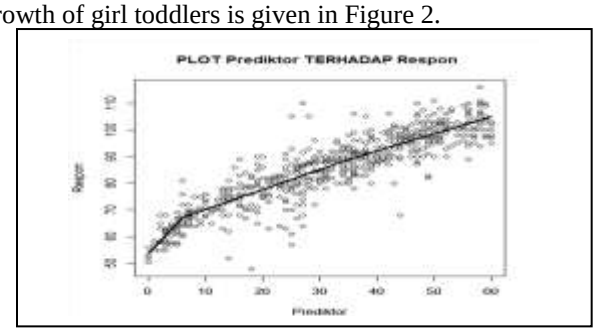

Figure 2. Plot of H/A median growth of girl toddlers.

Figure 2 shows that height of girl toddlers aged less than 6 months, and $6\text{ months} \leq \text{aged} < 36\text{ months}$, and also aged ≥ 36 months all tend to have sharply uptrend.

Estimating Median Growth of Girls Based on BMI/A

Also for this case, by applying equations (1) – (6) on the data of BMI/A girl toddlers, we obtain order one spline, two knots namely 6 and 36, minimum GCV value of 4.193948, coefficient of determination (R^2) of 0.1021295, $\widehat{\boldsymbol{\beta}} = (15.3165\,, 0.2488163\ , -0.2782231\ , -0.03725879\ )^T$, and MSE = 4.145463. Hence, we get the estimated spline model for BMI/A median growth of girl toddlers as follows:

$$\hat{y} = 15.32 + 0.25x - 0.28(x-6)_+ - 0.04(x-36)_+ \quad (11)$$

Equation (11) can be expressed as follows:

$$\hat{y} = \begin{cases} 15.32 + 0.25x\ ; x < 6 \\ 17 - 0.03x\ ; 6 \leq x < 36 \\ 18.44 - 0.07x\ ; x \geq 36 \end{cases} \quad (12)$$

So, plot of the estimated spline model for BMI/A median growth of girl toddlers is given in Figure 3.

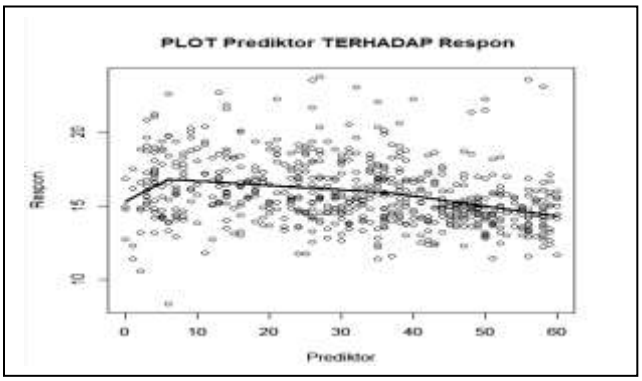

Figure 3. Plot of BMI/A median growth of girl toddlers.

Figure 3 shows that BMI of girl toddlers aged less than 6 months tend to have sharply uptrend, and then for BMI of girl toddlers $6\text{ months} \leq \text{aged} < 36\text{ months}$ and $\text{aged} \geq 36$ months all tend to have sharply downward trend.

3.2 Estimating for Boy Toddlers

The estimating median growth of boy toddlers consist of estimating median growth of boys based on W/A, H/A, and BMI/A.

Estimating Median Growth of Boys Based on W/A

To get estimating result of median growth of boy toddlers based on weight-for-age (W/A) using spline estimator, we apply equations (1) – (6) to the data of toddlers. The results give one order of spline, one knot namely 6 , $\widehat{\boldsymbol{\beta}} = (5.006321\,, 0.5730041\ , -0.4252202\ )^T$, minimum GCV value of 4.79083, MSE value of 4.747376, and coefficient of determination (R^2) of 0.5874209.

Hence, we have the estimated order one spline model of median growth of boy toddlers for W/A as follows:

$$\hat{y} = 5.01 + 0.57x - 0.43(x-6)_+ \quad (13)$$

We can express the equation (13) as follows:

$$\hat{y} = \begin{cases} 5.01 + 0.57x\ ; x < 6 \\ 7.59 + 0.14x\ ;\ x \geq 6 \end{cases} \quad (14)$$

Next, plot of the estimated spline model for W/A median growth of boy toddlers is given in Figure 4.

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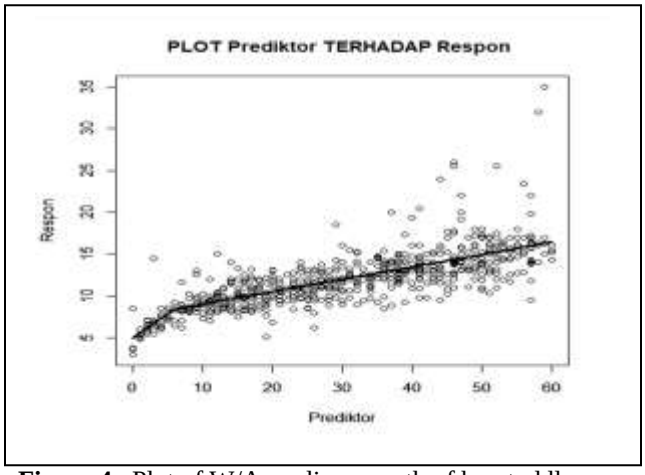

Figure 4. Plot of W/A median growth of boy toddlers.

Figure 4 shows that weight of boy toddlers aged less than 6 months and aged more than 6 months tend to have sharply uptrend.

Estimating Median Growth of Boys Based on H/A

Similarly, by applying equations (1) – (6) on the data of H/A boy toddlers, we obtain order one spline, two knots namely 6 and 36, minimum GCV value of 38.00017, MSE = 37.53956, coefficient of determination (R^2) of 0.7826179 and $\hat{\boldsymbol{\beta}} = (55.52561\,, 2.399439\;\;, -1.684954\;\;, -0.145033\,)^T$.

Hence, we have the estimated order one spline model of median growth of boy toddlers for H/A as follows:

$$\hat{y} = 55.53 + 2.4x - 1.68(x-6)_+ - 0.15(x-36)_+ \quad (15)$$

Hence, we have:

$$\hat{y} = \begin{cases} 55.53 + 2.4x\,; x < 6 \\ 65.61 + 0.72x\,; 6 \le x < 36 \\ 71.01 + 0.57x\,; x \ge 36 \end{cases} \quad (16)$$

Next, plot of the estimated spline model for H/A median growth of boy toddlers is given in Figure 5.

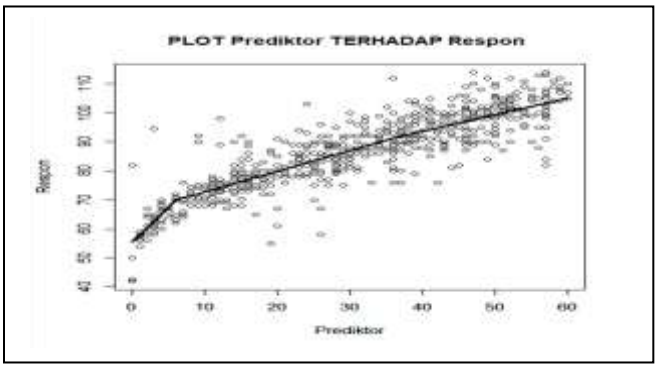

Figure 5. Plot of H/A median growth of boy toddlers.

Figure 5 shows that height of boy toddlers aged less than 6 months and $6\,\text{months} \le \text{aged} < 36\,\text{months}$ and also aged ≥ 36 months all tend to have sharply uptrend.

Estimating Median Growth of Boys Based on BMI/A

Similarly, by applying equations (1) – (6) on the data of BMI/A boy toddlers, we obtain order one spline, two knots namely 6 and 36, minimum GCV value of = 4.821935, coefficient of determination (R^2) of 0.1178849, $\hat{\boldsymbol{\beta}} = (16.40079\,, 0.191825\,, -0.2660097, 0.0615171)^T$, and MSE = 4.763399. Hence, we get the estimated spline model for BMI/A median growth of boy toddlers as follows:

$$\hat{y} = 16.4 + 0.19x - 0.27(x-6)_+ + 0.06(x-36)_+ \quad (17)$$

So, we can express equation (17) as follows:

$$\hat{y} = \begin{cases} 16.4 + 0.19x\,; x < 6 \\ 18.02 - 0.08x\,; 6 \le x < 36 \\ 15.86 - 0.02x\,; x \ge 36 \end{cases} \quad (18)$$

Next, plot of the estimated spline model for BMI/A median growth of boy toddlers is given in Figure 6.

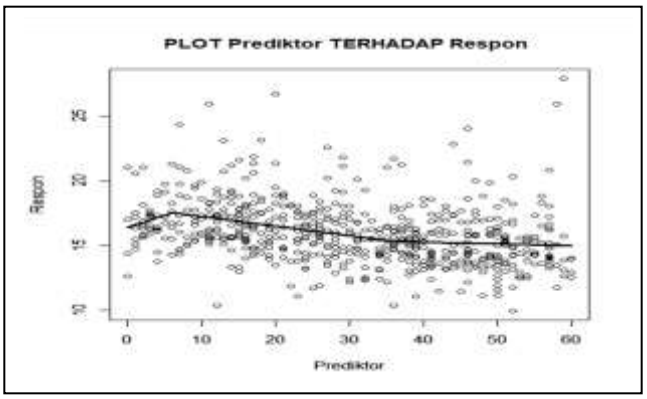

Figure 6. Plot of BMI/A median growth of boy toddlers.

Figure 6 shows that BMI of boy toddlers aged less than 6 months tend to have sharply uptrend, and for $6\,\text{months} \le \text{aged} < 36\,\text{months}$ the BMI of boy toddlers tend to have sharply downward trend and then for aged≥36 months the BMI of boy toddlers tend to have softly downward trend.

4. CONCLUSION

The results show that the toddlers growth of W/A, H/A, and BMI/A for both girls and boys of toddlers in sub-district Kertosari of Banyuwangi city that aged less than 6 months tend to have a sharply uptrend. Also, the toddlers growth of W/A and H/A for both girls and boys of toddlers in sub-district Kertosari of Banyuwangi city that aged more than 6 months tend to have a uptrend. Meanwhile, the toddlers growth of BMI/A for both boys and girls of toddlers in sub-district Kertosari of Banyuwangi city that aged more than 6 months tend to have a downward trend.

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