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Designing Standard Growth Chart for Toddlers of Banyuwangi Regency Using LS-Spline Nonparametric Regression

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Abstract: *Toddlers nutritional status are to be a health indicator of success in achieving Sustainable Development Goals (SDGs). In Indonesia, it is measured and recorded in a Towards Health Card (THC) every month at all Community Health Centers (CHCs). The CHC is available in each sub-district. The THC, which in Indonesia is called KMS, was created by referring WHO-2005 Standard Growth Chart (WHO-2005 SGC). Toddlers nutritional status is determined based on weight (W), height (H), and age (A) of toddlers and presented in the form of W/A (Weight-for-Age), H/A (Height-for-Age), and W/H (Weight-for-Height) or BMI/A (Body Mass Index-for-Age) which are three anthropometry indexes. This study aims to estimate median of toddlers weight growth, and to design a Banyuwangi Standard Growth Chart (BWI-SGC) for toddlers of Banyuwangi regency, one of regencies in Indonesia, based on recording data in CHCs of Banyuwangi regency which covers CHCs of Kertosari, Kabat, and Tampo districts. In this study we used a spline of least square in nonparametric regression model. The obtained results show that the weight of toddlers in Banyuwangi based on BWI-SGC is less than the weight of toddlers based on the WHO-2005 SGC, and the growth of girls is greater than the growth of boys.*

Keywords — Toddlers standard growth chart, LS-Spline, nonparametric regression model.

1. INTRODUCTION

In Indonesia a Community Health Center (CHC) is called as "Puskesmas" and in each district there is at least one CHC. Every CHC covers some Integrated Community Health Centers (ICHCs). In Indonesia, this ICHC is called "Posyandu" which is located in every village. Note that Kabat, a district in Banyuwangi regency, has twenty four villages. A CHC in Kabat covers eighty seven ICHCs. These are five ICHCs in Kabat Village, five ICHCs in Bunder Village, five ICHCs in Kedayunan Village, four ICHCs in Labanasem Village, five ICHCs in Gombolirang Village, five ICHCs in Tambong Village, five ICHCs in Bareng Village, twelve ICHCs in Macanputih Village, ten ICHCs in Pakistaji Village, six ICHCs in Pendarungan Village, five ICHCs in Pondoknongko Village, five ICHCs in Benelan Lor Village, seven ICHCs in Kalirejo Village, and ten ICHCs in Dadapan Village. While ICHC in Sub-District Tampo of Banyuwangi regency covers thirty one ICHCs namely eight ICHCs are located in Tampo Village, four ICHCs in Kaliploso Village, ten ICHCs in Plampangrejo Village, and nine ICHCs in Sembulung Village. Additionally, the data used in this study are data recorded by CHCs in Banyuwangi Regency of Indonesia consisting CHCs in Sub-District of Kertosari, CHCs in district of Kabat and CHCs in Sub-District of Tampo.

As we know that nutritional status of toddlers is used as a health indicator of successful measurement of SDGs achievement. We can determine the nutritional status of toddlers based on their weight (W), height (H), and age (A). They are presented in three indexes of anthropometry such as W/A, H/A and W/H or BMI/A. This means that a toddler who experiences lack of weight, height, and BMI is categorized as underweight. According to Health Department of Banyuwangi regency, there are amount 2,878 toddlers out of 42,597 total toddlers in Banyuwangi regency who are categorized as under-weight. In other word there are about 6.8% of toddlers in Banyuwangi regency who are categorized as under-weight [1].

Nutritional status of all toddlers in Indonesia are recorded in Towards Health Cards (THCs) called as "Kartu Menuju Sehat" (KMS). This THC was created based on the WHO-2005 anthropometric standard that contains curves of Z-Score for W/A, H/A, and BMI/A medians. The WHO-2005 SGC was designed by using samples considered can be able to represent the world regions and recommended as a global assessment for nutritional status. These samples were toddlers aged 0-60 months taken from the United State of America, Oman, Norway, India, Ghana, and Brazil [2-3]. These samples, of course, have different characteristic compared with toddlers of Indonesia. This fact will make a difference in chart patterns of the WHO-2005 SGC and BWI-SGC. To overcome the discrepancy, therefore we propose a design of local SGC based on samples of toddlers who have the same characteristic with toddlers in Indonesia especially in Banyuwangi regency. In further discussion, we call the proposed SGC as BWI-SGC. According to Cole [4], at each stage, the toddlers growth charts every age show different patterns. Since the pattern of toddlers growth curve does not indicate a particular shape of curve such as linear, so that the appropriate model approach to design BWI-SGC and analyze the data is Nonparametric Regression (NR) model where to estimate the model, we need an estimator. Recently, several estimators have been used for estimating the NR models, for examples kernel estimators and splines estimators [5–27] where one of these splines is least

square spline (LS-Spline) in which it can overcome data that have sharply rise or fall patterns by helping knots, and it gives relative smooth curve. Other estimators which are also often used for estimating the NR models are local polynomial estimators [28,29], and local linear estimators [30–34].

A research on designing locally SGCs of toddlers has been carried out by Yosefanny et al. [35] in one of cities in Sumatra. But the research has not differentiated underweight samples by sex yet. Furthermore, several researchers in Refs. [18,22,30,33] have differentiated underweight samples by sex, and the results of these researches showed that locally SGCs of toddler in East Java were smaller than the WHO-2005 SGC. Additionally, the SGC can also be designed based on values of percentile such as median. Besides that we can also design the toddler SGC based on the Z-Score. The use of the Z-Score of median values provides advantages namely the results of calculation are accurate, and we can compare the results for each group of age and anthropometric index. It is because the assessment is based on values of standard deviation. Therefore, determining median values of W/A, H/A, and BMI/A by using Z-Score can be used to take the problem of malnutrition indication, and it is more optimal than systems of conventional [22].

To design a SGC of toddlers for W/A, H/A, and BMI/A by using a NR model approach, we employed four variables such as weight (W), height (H), BMI, and age (A) for each sex. Hereinafter, the SGC of toddlers can also be designed by using a Semiparametric Regression (SR) model approach. This SR model approach had been carried out by researchers in Refs. [18,21,22] to design a SGC of children aged under five year for determining wasting nutrition status based on LS-Spline estimator. Those researchers also showed that the growth of each different age of toddlers is to be a nonparametric component, while variable of toddler sex is a parametric component that is as a dummy variable. Based on the facts explained above, therefore, we are interested to design a Banyuwangi Standard Growth Chart (BWI-SGC) for toddlers of Banyuwangi regency by using least square spline NR model approach.

2. Materials and Methods

In this section, we provide overview of all material and methods briefly which are used in this study such as NR model, least square spline (LS-Spline) estimator, GCV, coefficient of determination (CoD), and data of toddlers weight.

2.1. Nonparametric Regression (NR) Model

NR model is a regression model which is used to describe association between response or dependent variable (*y*) and predictor or independent variable (*t*) where the pattern of the association which is represented by a curve of regression is unknown. In general, the NR model is presented by the following equation:

$$y_i = f(t_i) + \varepsilon_i\,; \quad i = 1,2,\dots,n \qquad (1)$$

where $f(t_i)$ is a regression curve that is to be estimated, and ε_i is an independent random error that has zero mean and variance σ^2 [5,7,31].

2.2. Least Square Spline (LS-Spline) Estimator

LS-Spline estimator are pieces of a polynomial with different polynomial segments joined together at τ_1, τ_2, dan τ_3 knots while guaranteeing its continuous [14,20]. In this case, the spline function follows the following equation:

$$f_\lambda(x) = \sum_{j=0}^{p+k} \beta_{\lambda j}\varphi_j(x) \qquad (2)$$

where $\lambda = (\tau_1, \tau_2, \dots, \tau_k)$ is knot points, $f_\lambda(x)$ is spline function of order p with number of knots k , $\beta_{\lambda j}$ is parameter of LS-Spline, and $\varphi_j(x)$, $j = 0, 1, \dots, p+k$ are functions defined as follows:

$$\varphi_j(x) = \begin{cases} x^j & \text{for } x \geq \tau_{j-p} \\ (x-\tau_{j-p})_+^p & \text{for } x < \tau_{j-p} \end{cases}$$

and

$$(x-\tau_{j-p})_+^p = \begin{cases} (x-\tau_{j-p})^p & \text{for } x \geq \tau_{j-p} \\ 0 & \text{for } x < \tau_{j-p} \end{cases}.$$

2.3. Generalized Cross Validation (GCV)

In the NR modeling, to find the optimal spline regression function, we use GCV criterion. The GCV is used to obtain the optimal knot points [12,21]. The GCV is one of the methods for selecting the optimal knot point. The GCV values of the LS-Spline in the NR model are obtained by using the GCV equation as follows:

$$GCV(\lambda) = \frac{MSE\,(\lambda)}{\left(\frac{1}{n}tr[I-H(\lambda)]\right)^2} \qquad (3)$$

where $\lambda = p, \tau_1, \tau_2, \dots, \tau_k$ are smoothing parameters, p represents order of spline, k represents the number of knot points, and $\boldsymbol{H}(\lambda) = \boldsymbol{X}(\boldsymbol{X^t X} + \lambda \boldsymbol{D})^{-1}\boldsymbol{X^t}$ represents a hat matrix. In this step, we can derive the optimal value of knots based on the GCV criterion outlined in (3). In other word, we select a minimum GCV value of an observation points combination assumed to begin to change patterns of behavior.

2.4. Coefficient of Determination (CoD)

The CoD notated by R^2 describes a regression function accuracy measurement [31]. The purpose we calculate R^2 value is to determine the variation of the response or dependent variable (*y*) that can be explained by the predictor or independent variable (*x*) together. We can calculate the CoD value by using the formula given in (4) as follows:

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{\sum_{i=1}^n (y_i - \bar{y})^2} \qquad (4)$$

where $SSR = \sum_{i=1}^n (y_i - \bar{y})^2 - SSE$ represents sum squared of regression, $SSE = \sum_{i=1}^n (y_i - \hat{f}(t_i))^2$ represents sum squared of errors, $SST = \sum_{i=1}^n (y_i - \bar{y})^2$ represents sum squared of total, and $0 \leq R^2 \leq 1$.

2.5. Data of Toddlers Weight

In this study we used secondary data. The data consists of body weight and gender of toddlers that are children aged 0–60 months obtained from three CHCs in Banyuwangi regency

of Indonesia. We conducted data collection in 2023 at the CHCs of Kabat district, Kertosari district, and Tampo sub-district. In this step we used non-probability sampling with purposive sampling techniques, because we determined the sampling. To design the BWI-SGC, we used sample of toddlers passed from the screening process according to the WHO-2005 SGC based on criteria for conditions of maternal and child, environmental, and economic. We obtained the cross-sectional data amounted to 2,490 observations consisting of 1,232 observations for boy children aged under five years, and 1,258 observations for girl children aged under five years.

3. Results and Discussion

In the following, we present the results and discussion of our study. The results of calculation on order spline, knot points, minimum GCV, MSE, and coefficient of determination (R^2) for boy and girl are presented in Table 1.

Table 1. Values of order spline, knot points, minimum GCV, MSE, and coefficient of determination (R^2) for boy and girl.

Toddlers	Orde	Knot Points	Minimum GCV	MSE	R^2
Boy	2	6 , 12	0.099200	0.0836 0471	0.99 073
Girl	2	6 , 12	0.111355	0.0938 488	0.99 108

Table 1 shows that all toddlers (i.e., both boy and girl) have the same number of optimal orde namely 2, and the same optimal knot points namely 6 and 12.

Next, based on values of order spline, knot points, minimum GCV, MSE, and coefficient of determination (R2) for boy and girl presented in Table 1 that are values obtained by using LS-Spline NR model approach, we obtain the estimated LS-Spline NR model of W/A for boy toddlers as given by Equation (8), and the estimated LS-Spline NR model of W/A girl toddlers as given by Equation (9).

$$\hat{y} = \begin{cases} 3.506243 + 0.9459311x - 0.04668307x^2 & \text{for } x < 6 \\ 4.52277068 + 0.60708854x - 0.01844619x^2 & \text{for } 6 \le x < 12 \\ 7.09920284 + 0.17768318 - 0.0005543x^2 & \text{for } x \ge 12 \end{cases} \quad (8)$$

$$\hat{y} = \begin{cases} 3.473474 + 0.8616497x - 0.04540274x^2 & \text{for } x < 6 \\ 4.72745084 + 0.44365742x - 0.01057005x^2 & \text{for } 6 \le x < 12 \\ 6.155854376 + 0.205590164 - 0.000650581x^2 & \text{for } x \ge 12 \end{cases} \quad (9)$$

Hence, we use these estimated models given in Equations (8) and (9) to create a plot of the estimated LS-Spline NR model of W/A for boy toddlers (see Figure 1), and a plot of the estimated LS-Spline NR model of W/A for girl toddlers (see Figure 2).

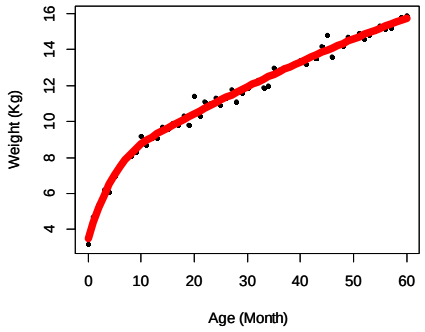

Figure 1. Plot of the estimated LS-Spline NR model of W/A for boy toddlers.

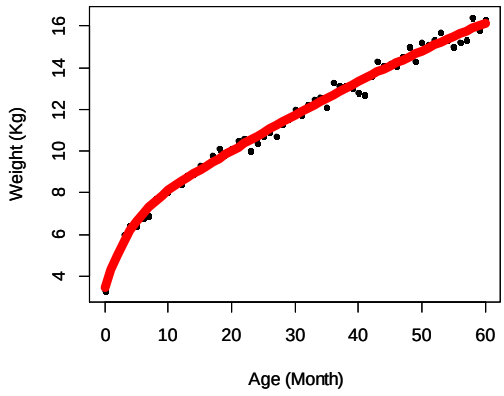

Figure 2. Plot of the estimated LS-Spline NR model of W/A for girl toddlers.

Next, comparison of the estimated LS-Spline NR model of W/A between boy toddlers and girl toddlers is presented in Figure 3.

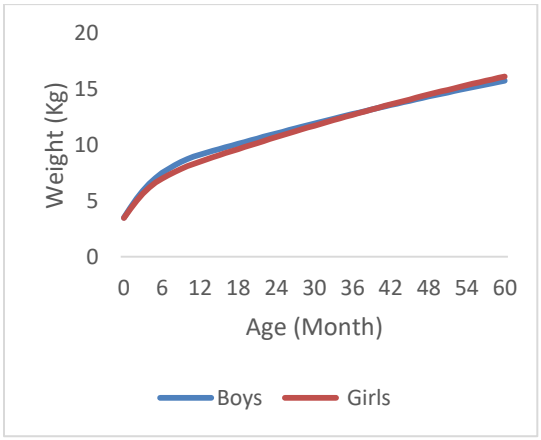

Figure 3. Comparison plot of the estimated LS-Spline NRmodel of W/A between boy toddlers and girl toddlers.

Figure 3 shows that the estimation of W/A for girl toddlers is higher than the estimation of W/A for boy toddlers.

Furthermore, these obtained estimation results by using LS-Spline NR model approach are then compared with the estimation results based on WHO-2005 SGC. The results are presented in Figures 4 and 5.

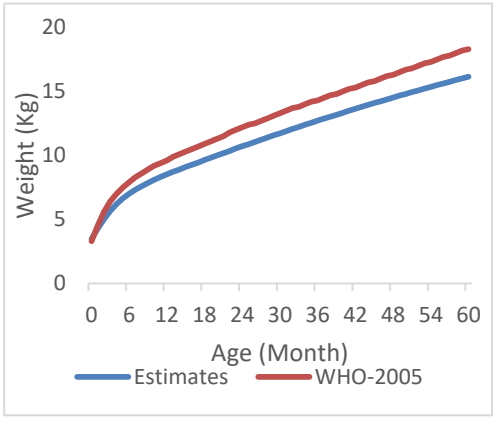

Figure 4. Plot of comparison between the estimated of W/A for girl toddlers in Banyuwangi based on LS-Spline NR model (blue line) and Based on WHO-2005 (red line).

From Figure 4, we can see that the estimated of W/A for girl toddlers in Banyuwangi regency based on LS-Spline NR model (called as BWI-SGC) are smaller than the estimated of W/A for girl toddlers based on WHO-2005 standard growth charts (called as WHO-2005 SGC).

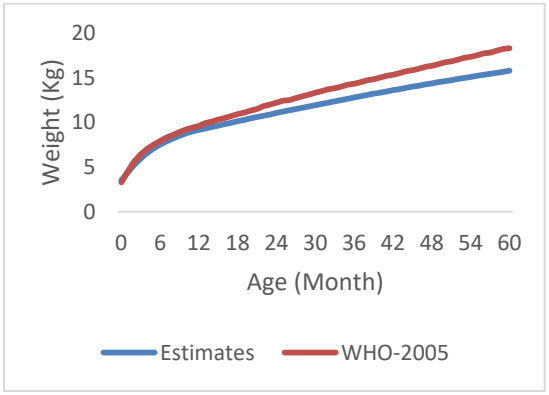

Figure 5. Plot of comparison between the estimated of W/A for boy toddlers in Banyuwangi based on LS-Spline NR model (blue line) and Based on WHO-2005 (red line).

Figure 5 we can see that the estimated of W/A for boy toddlers in Banyuwangi regency based on LS-Spline NR model (called as BWI-SGC) are smaller than the estimated of W/A for boy toddlers based on WHO-2005 standard growth charts (called as WHO-2005 SGC).

4. Conclusion

In this case, for toddlers of Banyuwangi regency, the growth based on W/A of girls are greater than the growth based on W/A of boys. However, the growth of boys and girls are increasing along with their ages. In addition, the estimated of W/A for girl toddlers and boy toddlers based on BWI-SGC are smaller than the estimated of W/A for girl toddlers and boy toddlers based on WHO-2005 SGC.

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