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THE DESIGN OF STANDARD GRAPH FOR TODDLER GROWTH USES NONPARAMETRIC PENALIZED SPLINE REGRESSION

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ABSTRACT

One way to carry out early detection of toddler growth is through the Healthy Way Card (KMS). The KMS used in Indonesia does not describe the growth behavior of toddlers. The KMS used is the standard from the World Health Organization (WHO). Apart from that, the growth chart for toddlers at each age will show different patterns. This pattern does not form a linear graph or a particular pattern. Therefore, the Nonparametric Regression method was used using a penalized spline estimator which produces a local Indonesian standard KMS which is used to assess the growth of toddlers. Designing KMS with a confidence interval approach to nonparametric regression values using a penalized spline estimator. Data was obtained from the results of the recapitulation of Posyandu in Bojonegoro from January to December 2023, totaling 120 data. The variables used in this research are the toddler's weight (y) as the response variable and the toddler's age (x) as the predictor variable. In nonparametric regression modeling using a penalized spline estimator with several combinations of numbers and knot point locations. Selection of optimal knot points using minimum Generalized Cross Validation (GCV). Based on the results of the analysis, it shows that there are different times of weight change for male toddlers and female toddlers in Bojonegoro. The weight of male toddlers in Bojonegoro has 3 patterns of change, namely the weight of male toddlers increases drastically until the age of 16 months, then increases slowly until the age of 55 months. Then the weight of male toddlers will increase again drastically after the age of 55 months. Meanwhile, the weight of female toddlers in Bojonegoro has three patterns of change, namely the weight of female toddlers increases drastically until the age of 5 months, then increases slowly until the age of 15 months, and again increases drastically after the age of 15 months. This can be caused by physical differences in babies based on gender. To create a standard chart for toddlers' weight growth based on age, it was analyzed by calculating the percentile values consisting of P_3, P_{15}, P_{50}, P_{85}, and P_{97} for each toddler age category.

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1. INTRODUCTION

The toddler years are a developmental period that is vulnerable to nutritional problems. Early detection of toddler growth needs to be done to find deviations in their growth and development [1]–[4]. If deviations or growth and development problems in toddlers can be detected early, then intervention will be easier to carry out [5]–[7]. One way to detect early growth in toddlers is through the Healthy Way Card (KMS). KMS is an instrument that contains the normal growth curve of toddlers based on the anthropological index of weight for age (WW/U) [8]–[11]. However, the KMS used in Indonesia does not describe the growth behavior of toddlers. This is because the KMS used is the standard from the World Health Organization (WHO) issued by the National Center Health Statistics (NCHS) which is based on the Z-Score standard growth chart of body weight for age with the samples taken from India, Brazil, Norway, Ghana, United States, and Oman [12]–[15]. Therefore, there are differences in the physical characteristics of Indonesian toddlers and the toddlers used by WHO. This causes differences between the WHO standard growth chart pattern and the Indonesian standard growth chart pattern [10][16][17]. As a result, some toddlers should be healthy, but in the KMS they are detected as unhealthy and vice versa. Therefore, to overcome this problem, a KMS was designed locally using data on Indonesian toddlers. Apart from that, the growth charts for toddlers at each age will show different patterns [18]–[20]. This pattern does not form a linear graph or a particular pattern. The flexible nature of data makes nonparametric regression suitable for use on data that does not have a specific model [21][22].

In nonparametric regression, several estimators include truncated spline, smoothing spline, and penalized spline [23][24]. Splines are polynomial pieces with segmented and continuous properties and a certain order at each knot point. Knot points are fusion points that occur because there are changes in behavioral patterns at different intervals [25][26]. From these knot points it can be used to obtain an optimal mathematical model. The advantage of the penalized spline estimator compared to truncated spline is the ability to estimate more accurately because it involves knot points and smoothing parameters simultaneously in controlling the smoothness of the curve [27]–[29]. Penalized spline also has advantages compared to

smoothing spline, which can overcome overfitting models if there are a lot of them too many knots are used with added penalties/constraints on the spline parameters with the aim of avoiding excess knots [30]. Penalized spline, namely regression obtained based on squares smallest (least square) with a roughness penalty. Penalized spline has many similarities to spline smoothing, but the type of penalty used in penalized splines is more common than in smoothing splines [31].

In previous research, it was conducted about designing KMS based on toddler weight using least square spline semiparametric regression. This research shows that KMS gave a lower reference than WHO standard growth chart such that percentage of malnutrition and less-nutrition status categories provided by KMS was also lower than those by WHO standard growth chart [15]. Apart from that, other research about designing KMS based on weight for age Z-Score Using Least-Square Spline Estimator. This research shows that KMS are more suitable to be used to assess the nutritional status of children, because they can better explain the real conditions of children in East Java, Indonesia than the WHO standard growth charts [32].

The novelty and aim of this research is to design KMS as an early detection of growth problems in toddlers. Early detection of toddler growth is based on the Nonparametric Regression method using a penalized spline estimator which produces a local Indonesian standard KMS which is used to assess toddler growth. This research is expected to produce an innovation from the Nonparametric Regression method for early detection of toddler growth in the form of a KMS design. Next, parents can get the KMS to get the nutritional status of their toddlers, whether they are underweight or malnourished, which is an indicator of stunting. In the end, this research helps all parties handle and prevent problems with toddler growth, especially stunting.

2. RESEARCH METHODS

2.1 Data Source

The data used in this research is secondary data regarding toddler age (months) and toddler weight (kilograms). Data was obtained from the results of the recapitulation of Posyandu in Bojonegoro district that is Flamboyant Posyandu, Jasmine Park Posyandu, Melati Pungpungan village Posyandu, Cempaka Posyandu, dahlia Posyandu and orchid park Posyandu. The data obtained are weight measurements of infants aged 0 up to 60 months based on gender. There are 60 data observations of male infants and 60 data observations of female infants. Thus, the total data used is 120.

2.2 Research Variables

The variables used in this research are the toddler's weight (y) as the response variable and the toddler's age (x) as the predictor variable.

2.3 Research Procedure

The analysis steps in this research are as follows:

1. Divide the data based on the gender of the toddler, each consisting of 60 data
2. Create a scatter diagram to see the data distribution pattern between toddler age (x) and toddler weight (y)
3. Carry out nonparametric regression modeling using a penalized spline estimator with several combinations of numbers and knot point locations. In general, the nonparametric regression model can be written in **Equation (1)**:

$$y_i = f(x_i) + \varepsilon_i; \quad i = 1,2,3, \dots, n \tag{1}$$

   where ε_i is the ith error which is assumed to have the distribution $N(0, \sigma^2)$, and $f(x_i)$ is the regression function whose pattern form is unknown [33]–[36]. A spline function of order m with knot points $K_1, K_2, \dots, K_N$, is defined as any function f presented in **Equation (2)**:

$$f_{(x)} = \sum_{j=1}^{m} \beta_j \, x_i^j + \sum_{k=1}^{N} \beta_{m+k} \, (x_i - K_k)_+^m \tag{2}$$

   where

$$(x_i - K_k)_+^m = \begin{cases} (x_i - K_k)^m, x \geq K_k \\ 0, x < K_k \end{cases} \tag{3}$$

4. Selection of optimal knot points using minimum Generalized Cross Validation (GCV) [25][37]. In the spline model, the GCV criteria are defined as shown in **Equation (4)**:

$$GCV(\lambda) = \frac{MSE(\lambda)}{\left[n^{-1} tr\left(I - A(\lambda)\right)\right]^2} \tag{4}$$

   where

$$\mathbf{A}(\boldsymbol{\lambda}) = \mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}' \tag{5}$$

$$MSE(\lambda) = n^{-1} \sum_{i=1}^{n} \left(y_i - f_\lambda(x_i)\right)^2 \tag{6}$$

5. Create a nonparametric regression equation using a penalized spline estimator based on selecting optimal knot points. The knot point is a focus point in the spline function such that the curve formed is segmented at that point. Knot points are important in the nonparametric penalized spline regression model [25][37]. The number of knot points K as shown in **Equation (7)**:

$$Min\left\{\frac{1}{4} \times \text{the number of unique data sample}, 35\right\} \tag{7}$$

6. Create a nonparametric regression estimation curve using a penalized spline estimator
7. Testing the significance of nonparametric regression parameters using a penalized spline estimator simultaneously (simultaneously) using the F-test and individually (partially) using the t-test [29].

8. Designing KMS with a confidence interval approach to nonparametric regression values using a penalized spline estimator [27][29]. The confidence interval of the average of the dependent variable at a certain point, such as $x_{11}, x_{12}, \ldots, x_{1k}$, with vector x_i can be written in Equation (8)

$$X_{(k+1)*1} = \begin{bmatrix} 1 \\ x_{11} \\ x_{12} \\ \vdots \\ x_{1k} \end{bmatrix} \tag{8}$$

The exact value at points $x_{11}, x_{12}, \ldots, x_{1k}$ can be expressed in Equation (9):

$$\hat{y}_i = x_i^T \hat{\beta} \tag{9}$$

Thus, the confidence interval (1-α)100% of the average predictor variable at points $x_{11}, x_{12}, \ldots, x_{1k}$ can be written in Equation (10):

$$\hat{y}_i - t_{\left(\frac{\alpha}{2}, n-p\right)}\sqrt{\hat{\sigma}^2 x_i^T (X^T X)^{-1} x_i} \le y_i \le \hat{y}_i + t_{\left(\frac{\alpha}{2}, n-p\right)}\sqrt{\hat{\sigma}^2 x_i^T (X^T X)^{-1} x_i} \tag{10}$$

3. RESULTS AND DISCUSSION

3.1 Model of Toddler Weight Growth in Bojonegoro with Approach Penalized Spline

The stages of modeling toddler weight based on age begin by dividing the data based on male and female gender, where the amount of data for male is 60 and the amount of data for female is 60. After dividing the data, the next step is to create a scatter diagram to see the relationship pattern between toddler weight and age as shown in Figure 1 and Figure 2.

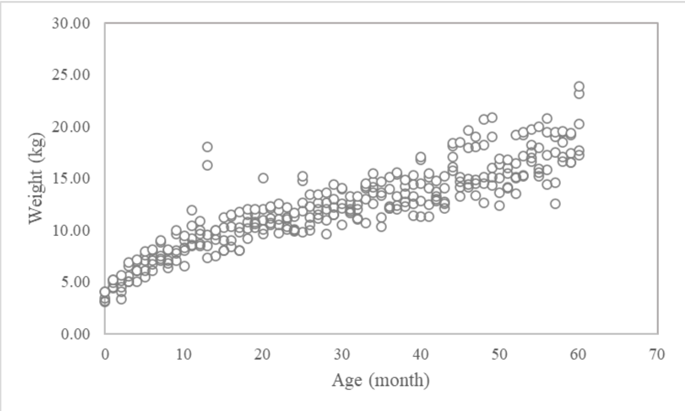

Figure 1. Scatter Diagram Between Toddler Weight and Age for Male Toddlers in Bojonegoro

Based on Figure 1, it can be seen that as the age of toddlers increases, the variation in body weight of toddlers, especially male, will also become greater. Apart from that, there are several outliers in the data, so the parametric estimation model cannot be used. Likewise, in Figure 2, it can be seen that as the age of toddlers increases, the variation in body weight of toddlers, especially female toddlers, will also become greater. Therefore, to model toddler growth based on the weight and age of toddlers in Bojonegoro for both male and female toddlers, a nonparametric regression approach was used. To get more accurate estimation results, a penalized spline estimator is used.

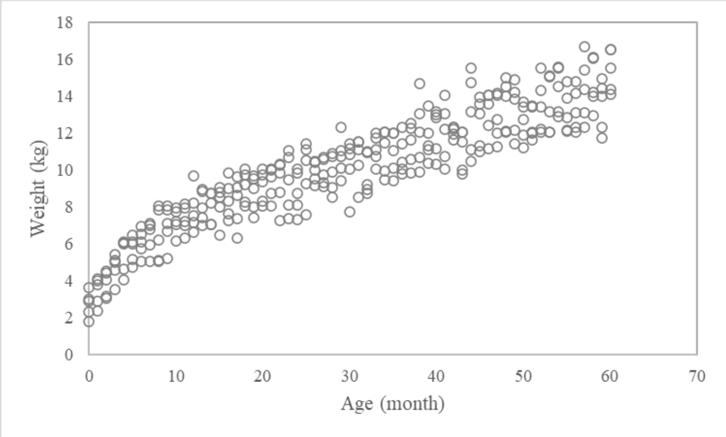

Figure 2. Scatter Diagram Between Toddler Weight and Age Among Female Toddlers in Bojonegoro

The penalized spline involves knot points, smoothing parameters, and spline order simultaneously. The optimal lambda value is obtained by looking at the graph between the minimum GCV and lambda values. The best model is obtained from the minimum GCV value and R^2 value at each knot point value. Based on the results of the analysis, the minimum GCV value for each lambda and knot point was obtained as shown in **Table 1** for male toddlers and **Table 2** for female toddlers.

Based on **Table 1**, the minimum GCV value is $4{,}76 \times 10^{-6}$ and the lambda value is 600. This shows that at this knot point an optimal nonparametric model will be produces. So that the optimal nonparametric regression model based on the penalized spline estimator is obtained in order $q = 2$ and two-knot points, namely $K_1 = 16$ and $K_2 = 55$. The resulting growth estimation model for male toddlers can be written in **Equation (11)**.

$$\hat{y} = 3.741 + 0.672x - 0.0169x^2 + 0.0181(X - 16)_+^2 + 0.00483(X - 55)_+^2 \quad (11)$$

Table 1. GCV Values of Lambda and Optimal Knot Points in Toddler Male

Number of Knots	Knot Point	Lambda	GCV
1	10	1400	4.92×10^{-6}
1	17	6500	4.77×10^{-6}
2	5, 20	5700	4.78×10^{-6}
2	**16, 55**	**600**	$\mathbf{4.76 \times 10^{-6}}$
3	5, 10, 30	9800	4.78×10^{-6}
3	15, 20, 50	75300	4.77×10^{-6}

The model in **Equation (11)** can be described in the following **Equation (12)**.

$$\hat{y} = \begin{cases} 3.741 + 0{,}672x - 0.0169x^2, & 0 \le x < 16 \\ 3.862 + 0.511x + 0.0116x^2, & 16 \le x < 55 \\ 5.973 - 0.437x + 0.0611x^2, & 55 \le x \end{cases} \quad (12)$$

The nonparametric penalized spline regression curve estimation plot is based on the optimal model for the weight growth of male toddlers as shown in **Figure 3**. Based on **Figure 3**, it can be seen that the weight of male toddlers in Bojonegoro has 3 patterns of change, namely the weight of male toddlers increases drastically until the age of 16 months, then increases slowly until the age of 55 months. Then the weight of male toddlers will increase again drastically after the age of 55 months.

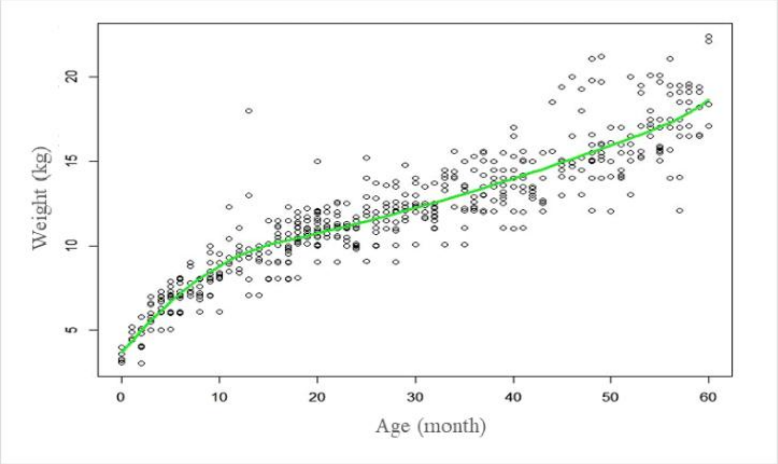

Figure 3. Estimated Plot of the Nonparametric Penalized Spline Regression Curve for Male Toddler

Furthermore, based on Table 2, the minimum GCV value is 2.13×10^{-6} and the lambda value is 600. This shows that at this knot point an optimal nonparametric model will be produces. So that, the optimal model for the growth of toddler weight according to the age of female toddlers was obtained with a quadratic pattern that occurred in the growth of female toddlers in Bojonegoro at two-knot points, namely 5 and 15.

Table 2. GCV Values of Lambda and Optimal Knot Points in Female Toddlers

Number of Knots	Knot Point	Lambda	GCV
1	10	1300	2.18×10^{-6}
1	40	58700	2.36×10^{-6}
2	**5, 15**	**600**	$\mathbf{2.13 \times 10^{-6}}$
2	30, 50	100900	2.29×10^{-6}
3	5, 10, 50	2800	2.15×10^{-6}
3	10, 20, 30	7200	2.15×10^{-6}

The results of estimating the weight growth of female toddlers using a nonparametric regression approach based on a penalized spline estimator with quadratic order are as follows in Equation (13)

$$\hat{y} = 3.163 + 0.556x - 0.0161x^2 + 0.00378(X-5)_+^2 + 0.0119(X-15)_+^2 \quad (13)$$

The model in Equation (13) can be described in the following Equation (14).

$$\hat{y} = \begin{cases} 3.163 + 0.556x - 0.0161x^2, & 0 \le x < 5 \\ 3.257 + 0.518x - 0.0122x^2, & 5 \le x < 15 \\ 5.933 + 0.162x - 0.0003x^2, & 15 \le x \end{cases} \quad (14)$$

The nonparametric penalized spline regression curve estimation plot is based on the optimal model for the weight growth of female toddlers as shown in Figure 4. Based on Figure 4, it can be seen that the weight of female toddlers in Bojonegoro has three patterns of change, namely the weight of female toddlers increases drastically until the age of 5 months, then increases slowly until the age of 15 months, and again increases drastically after the age of 15 months.

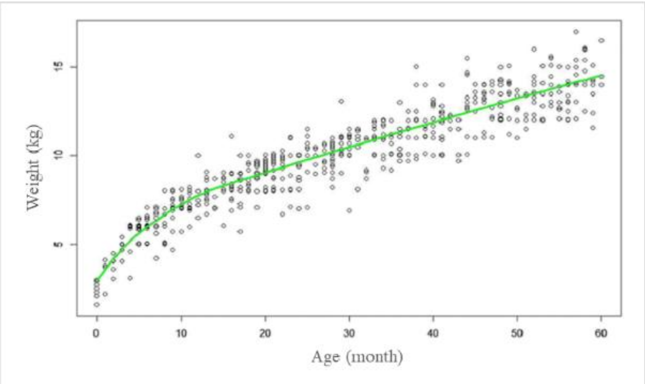

Figure 4. Estimated Plot of the Nonparametric Penalized Spline Regression Curve for Female Toddlers

Based on the results of the analysis, show that there are different times of weight change for male toddlers and female toddlers in Bojonegoro. This can be caused by physical differences in babies based on gender. To further analyze the growth of toddlers in Bojonegoro, this research created a standard KMS graph based on data analyzed using a penalized spline.

3.2 Design of a Standard Graph for Weight Growth According to the age of Toddlers in Bojonegoro

The creation of standard charts for toddler weight growth based on age was analyzed by calculating percentile values consisting of $P_3, P_{15}, P_{50}, P_{85}$, and P_{97} for each toddler age category. Selection of optimal knot and lambda points that contain the minimum GCV and R^2 values at each percentile value as shown in **Table 3** for male toddlers and **Table 4** for female toddlers.

Table 3. Minimum GCV Value of Lambda and Optimal Knot Point at Each Percentile for Male Toddler

Percentile	Number of Knots	Knot Point	Optimal Lambda	Minimum GCV	R^2
3	1	25	12000	2.31×10^{-4}	0.933
15	2	10, 35	1700	1.48×10^{-4}	0.957
50	2	15, 50	1600	1.49×10^{-4}	0.956
85	2	15, 54	1200	4.45×10^{-4}	0.904
97	2	3, 16	3400	5.98×10^{-4}	0.892

Based on **Table 3**, the estimated results of the $P_3, P_{15}, P_{50}, P_{85}$, and P_{97} percentile values for male toddlers are as follows.

$$\hat{y}_3 = 3.688 + 0.391x - 0.00528x^2 + 0.00642(X-25)_+^2$$
$$\hat{y}_{15} = 4.159 + 0.400x - 0.00626x^2 + 0.00312(X-10)_+^2 + 0.00547(X-35)_+^2$$
$$\hat{y}_{50} = 4.539 + 0.462x - 0.00893x^2 + 0.00864(X-15)_+^2 + 0.00487(X-50)_+^2$$
$$\hat{y}_{85} = 5.266 + 0.537x - 0.0121x^2 + 0.0129(X-15)_+^2 + 0.00196(X-54)_+^2$$
$$\hat{y}_{97} = 5.252 + 0.609x - 0.0136x^2 + 0.00029(X-3)_+^2 + 0.0141(X-16)_+^2$$

Next, the estimation results are outlined in a draft reference chart for the growth of male toddlers' weight as shown in **Figure 5** below.

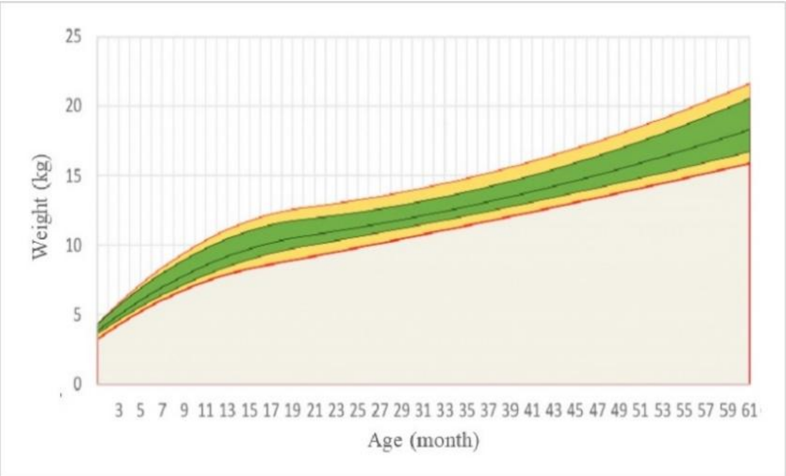

Figure 5. Design of Growth Chart for Male Toddler

Based on **Figure 5**, the green area at P_{15} to P_{85} identifies the nutritional status of normal toddlers. At P_3 to P_{15}, the color area in yellow can be interpreted as the nutritional status of underweight toddlers, while at P_{85} to P_{97} the color area in yellow can be interpreted as the nutritional status of fat. At P_3 and below, the gray area identifies the nutritional status of very thin toddlers, and the white area at P_{97} and above identifies the nutritional status of very fat toddlers.

Table 4. Minimum GCV Values of Lambda and Optimal Knot Points at Each Percentile for Female Toddlers

Percentile	Number of Knots	Knot Point	Optimal Lambda	Minimum GCV	R^2
3	2	5, 14	2300	7.39×10^{-5}	0.964
15	2	10, 50	800	6.98×10^{-5}	0.959
50	2	5, 20	100	9.41×10^{-5}	0.962
85	2	3, 11	700	7.45×10^{-5}	0.965
97	2	5, 12	1600	1.19×10^{-4}	0.954

Based on **Table 4**, the estimated results of the $P_3, P_{15}, P_{50}, P_{85}$, and P_{97} percentile values for female toddlers are as follows.

$$\hat{y}_3 = 2.689 + 0.371x - 0.00771x^2 + 0.00076(X-5)_+^2 + 0.00628(X-14)_+^2$$
$$\hat{y}_{15} = 3.466 + 0.335x - 0.00625x^2 + 0.00472(X-10)_+^2 + 0.00265(X-50)_+^2$$
$$\hat{y}_{50} = 3.831 + 0.384x - 0.00631x^2 + 0.00069(X-5)_+^2 + 0.00511(X-20)_+^2$$
$$\hat{y}_{85} = 4.392 + 0.382x - 0.00766x^2 + 0.00033(X-3)_+^2 + 0.006(X-11)_+^2$$
$$\hat{y}_{97} = 4.429 + 0.426x - 0.00935x^2 + 0.00111(X-5)_+^2 + 0.00697(X-14)_+^2$$

Next, the estimation results are outlined in a draft reference chart for the growth of female toddlers weight as shown in **Figure 6** below.

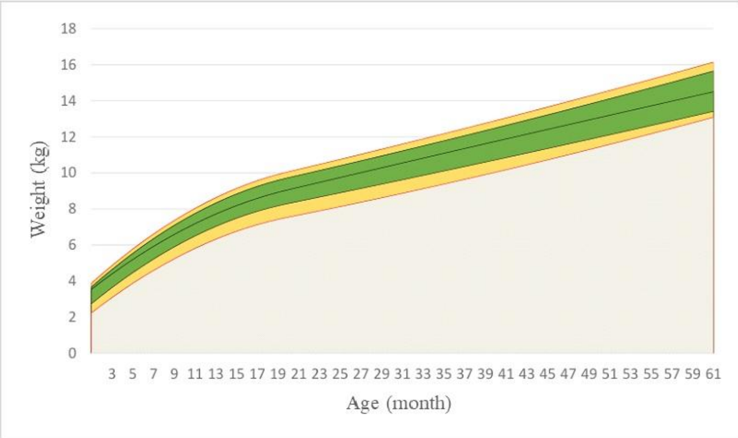

Figure 6. Design of Growth Chart for Male Toddler

Based on **Figure 6**, Design of growth chart for male toddler in Bojonegoro using nonparametric regression methods penalized spline is divided into 5 intervals of toddler nutritional status. Green color area those at P_{15} to P_{85} identify nutritional status normal toddler. At P_3 to P_{15} the color area is yellow means that the nutritional status of toddlers is thin, while at P_{85} to P_{97} the yellow area means that the nutritional status is fat. On P_3 up to the bottom with the gray area identifying the nutritional status of very thin toddlers and the white area at P_{97} up to the top identifying the nutritional status of very fat toddlers.

4. CONCLUSIONS

Based on the results of the analysis, show that there are different times of weight change for male toddlers and female toddlers in Bojonegoro. This can be caused by physical differences in babies based on gender. The nonparametric penalized spline regression curve estimation plot is based on the optimal model for the weight growth of male toddlers show that the weight of male toddlers in Bojonegoro has three patterns of change, namely the weight of male toddlers increases drastically until the age of 16 months, then increases slowly until the age of 55 months. Then the weight of male toddlers will increase again drastically after the age of 55 months. Meanwhile, the weight of female toddlers in Bojonegoro has three patterns of change, namely the weight of female toddlers increases drastically until the age of 5 months, then increases slowly until the age of 15 months, and again increases drastically after the age of 15 months.

Design of toddler weight growth graph according to toddler age in Bojonegoro using nonparametric regression methods penalized spline is divided into 5 intervals of toddler nutritional status. Green color area

those between P_{15} to P_{85} identify nutritional status, normal toddler. Up to you with the yellow area color can be interpreted as the nutritional status of underweight toddlers, whereas in up to you The yellow area can be interpreted as fat nutritional status. Down to the bottom with the gray area identifying the nutritional status of very thin toddlers and the white area identifying the nutritional status of very obese toddlers. Furthermore, in the process of determining the nutritional status of toddlers, the government hopes that Indonesia, especially the Bojonegoro district government, has standards for the toddler's own growth in accordance with the situation and conditions of the toddler in Bojonegoro. In future research, researchers are expected to increase the number of samples as well as considering other variables such as height or size toddler's head circumference to get maximum results.

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