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Standard Growth Charts for Weight of Children in East Java Using Local Linear Estimator

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Abstract. Health Card that is in Indonesia called as Kartu Menuju Sehat (KMS) is used to assess nutritional status of children up to five years old. The anthropometric index recorded in the Health Card is weight for age. The goal of this paper is to design standard growth charts for both boy and girl of weight for age of children in East Java, Indonesia. These growth charts are used to assess nutritional status of children in East Java, Indonesia. The rate of growth of weight is not the same for every interval of ages. For this case, the using of local linear estimator is suitable to design standard growth charts of weight for age of children up to five years old. The results show that the average values of R-square are 99.72% for boy and 99.73% for girl. Also, the average values of mean square error are 0.02758 for boy and 0.02976 for girl. In addition, the standard growth charts for both boy and girl of weight for age of children up to five years old in East Java, Indonesia is lower than those of WHO-2005 standard charts.

1. Introduction

There are some researches who have studied the children growth chart. [1] conducted a study which showed that the average weight infants tended to avoid the standard median WHO 2005 after 9 months in girls and after 6 months in boys. Research in the United Kingdom suggest to use a standard infant growth charts locally if it is available [2]. It aims to adjust the infant growth environment with socio-economic background of the local area. Similar researches related to standard growth charts locally in Surabaya conducted by [3] using multi-response local polynomial modeling, [4] using kernel smoothing in multi-response nonparametric regression, [5] using bi-response semiparametric regression approach based on P-Spline estimator, and [6-7] using local linear estimator in bi-response nonparametric and semiparametric regression model for estimating median growth charts of children.

Based on Indonesia Health Profile Year 2016, cases of malnutrition status of children aged 0 - 59 months in the category of severely underweight still occur with an average of 3.4%. While underweight cases still occur with an average of 13.9%. According to Health Department the Province of East Java, Indonesia that during 2013 - 2015, East Java Province had the highest number of malnutrition cases in Java. It had been found 6,749 cases in 2013, 6,732 cases in 2014 and 6,015 cases in 2015 [8]. Up to now, the determining of nutritional status of children up to five years old uses an instrument called the Health Card (KMS). The information recorded on KMS is the weight anthropometric index based on age. The KMS used in Indonesia since 2008 has referred to WHO-
2005 standard charts. The WHO-2005 standard charts is the world's standard anthropometry of children up to five years old that was designed based on samples of children from Brazil, Ghana, India, Norway, Oman and the United States. The high cases of malnutrition status in East Java may be caused by the KMS evaluator standard used is less appropriate because children used by WHO-2005 standard charts is very different physically from children in Indonesia, especially children in East Java.

The estimator in nonparametric regression model that can accommodate locally condition of growth curve of children up to five years old is local linear estimator. The advantages of this estimator are able to estimate the function at each point such that the model closes to the real pattern, and also no need much data to estimate the model [9]. In this paper, we are interested to design the standard growth charts of weight for age of children up to five years old in East Java by using local linear estimator approach. Next, designing of local linear standard growth charts will be used to determine the nutritional status of children up to five years old in East Java, and we compare the nutritional status of children up to five years old by using local linear standard growth charts with those by using WHO-2005 standard growth charts.

2. Local Linear Estimator

Suppose paired data of observations \((y_i, t_i)\) follows the nonparametric regression model:

\[ y_i = f(t_i) + \varepsilon_i, i = 1, 2, 3, \ldots, n \]  

(1)

where \(\varepsilon_i\) is a random error assumed to be independent with mean zero and variance \(\sigma^2\), and \(f\) is a regression function to be estimated. The regression function \((f)\) in (1) is estimated by a local linear estimator, so it can be expressed as follows:

\[ \hat{f}(t) = t(t_0) \hat{\beta}(t_0) \]  

(2)

where \(\hat{\beta}(t_0)\) is obtained by using weighted least square (WLS) method, i.e., by minimizing the following function:

\[ Q(t_0) = (y - Z(t_0) \beta(t_0))^T K_0(t_0) (y - Z(t_0) \beta(t_0)) \]  

(3)

and we get:

\[ \hat{\beta}(t_0) = (Z'(t_0) K_0(t_0) Z(t_0))^{-1} Z'(t_0) K_0(t_0) y \]  

(4)

Based on (2) and (4), the form of a local linear estimator for \((t)\) can be written as follows:

\[ \hat{f}(t) = t(t_0) Z'(t_0) K_0(t_0) Z(t_0))^{-1} Z'(t_0) K_0(t_0) y \]  

(5)

3. Cross Validation Method for Determining Optimal Bandwidth

Bandwidth \((h)\) is a smoothing parameter that controls the smoothness of curve. Cross validation (CV) method is one of the methods used to obtain the optimal bandwidth [10]. The optimal bandwidth \((h)\) is obtained based on the minimum value of CV that is formulated as follows:

\[ CV(h) = \min \frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{f}_{\alpha}^{(i)}(t_i))^2 \]  

(6)

where \(\hat{f}_{\alpha}^{(i)}(t_i) = t(t_0)(Z^{-1T}(t_0) K_0^{-1} (t_0) Z^{-1}(t_0))^{-1} Z^{-1T}(t_0) K_0^{-1} (t_0) y^{(-i)} \). The matrix \(Z^{-1}(t_0)\) is matrix \(Z(t_0)\) by omitting \(i^{th}\) observations, matrix \(K_0^{-1} (t_0)\) is the matrix \(K_0(t_0)\) by omitting \(i^{th}\) observations, and vector \(y^{(-i)}\) is vector \(y\) by omitting \(i^{th}\) observations.

4. Goodness of Fit

Mean square error (MSE) is derived from the mean of quadratic approximate difference estimator around the value of the actual population parameter. The value of MSE can be calculated through the following formula:
\[
MSE = n^{-1} \sum_{i=1}^{n} (y_i - \hat{m}(x_i))^2
\]

(7)

According to [11], the coefficient of determination \( R^2 \) draws the accuracy of the regression curve in order to know the variation of response variable \( y \) which can be explained by several predictor variables \( x \). The coefficient of determination can be calculated by the following formula [12].

\[
R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{m}(x_i))^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}
\]

(8)

5. Data and Steps of Analyze

The data used in this research are results of measuring weight based on age and gender of children up to five years old. The data is secondary data that was obtained from Public Health Care Center (called as PUSKESMAS) and Integrated Health Care Center (called as POSYANDU) in 16 cities in East Java, i.e., Madiun, Tulungagung, Nganjuk, Kediri, Bojonegoro, Mojokerto, Jombang, Lamongan, Malang, Jember, Surabaya, Sidoarjo, Gresik, Sampang, Probolinggo, and Banyuwangi. The data consists of 18,962 of boys and 17,967 of girls. To analyze the data, we conduct the following steps:

a. Based on WHO-2005 standard charts for assessing nutritional status of children up to five years old, we must calculate the percentile values \( (P_3, P_{15}, P_{50}, P_{85}, \text{and } P_{97}) \) of weight of children in every age group (month).

b. Determine the optimal bandwidth \( (h) \) based on the minimum CV value in each percentile value.

c. Estimate the weight standard charts in each percentile by using nonparametric local linear estimator regression approach.

d. Calculate the value of MSE and the coefficient of determination \( (R^2) \).

e. Design the standard growth chart of children up to five years old for weight based on age using local linear nonparametric regression approach.

f. Compare the nutritional status of children based on boy and girl using between local linear standard growth charts and WHO 2005 anthropometric standard charts.

For analyzing the data, we create code in Open Source Software (OSS)-R.

6. Result and Discussion

For designing standard growth charts of weight, we estimate curve of the percentile values, i.e., \(3^{rd}, 15^{th}, 50^{th}, 85^{th}, \text{and } 97^{th}\) of weight of children in every age group using local linear estimator. To estimate the curves, we determining the optimal bandwidth \( (h) \) based on the minimum CV criterion. The result of the optimal bandwidth \( (h) \) value based on the minimum CV criterion in every percentile is showed in Table 1 as follows:

| Gender | Percentile | Optimal Bandwidth | Minimum CV | MSE    | \( R^2 \) (%) |
|--------|------------|-------------------|------------|--------|---------------|
| Boy    | 3\(^{rd}\)  | 1.26              | 0.0629     | 0.0264 | 99.55         |
|        | 15\(^{th}\) | 0.86              | 0.0133     | 0.0038 | 99.95         |
|        | 50\(^{th}\) | 1.81              | 0.0447     | 0.0185 | 99.79         |
|        | 85\(^{th}\) | 1.50              | 0.0628     | 0.0288 | 99.77         |
|        | 97\(^{th}\) | 1.83              | 0.1400     | 0.0707 | 99.55         |
| Girl   | 3\(^{rd}\)  | 2.44              | 0.0586     | 0.0326 | 99.48         |
|        | 15\(^{th}\) | 0.23              | 0.0134     | 3.3196e-10 | 100          |
|        | 50\(^{th}\) | 1.13              | 0.0213     | 0.0081 | 99.91         |
Based on the result showed in Table 1, we get the average $R^2$ values of the estimation for both boy and girl of weight growth in every percentile, i.e., 99.72%, and 99.73%, respectively. Also, the average values of MSE are 0.02758 for boy and 0.02976 for girl. The estimated model in age 0, 6, 12, 24, 36, and 48 of median ($P_{50}$) growth curve of weight for both boy and girl is showed as follows:

For boy:  
$$ \hat{y} = \begin{cases} 3.584 + 0.912(t - t_0), & t_0 = 0 \\ 7.491 + 0.353(t - t_0), & t_0 = 6 \\ 9.041 + 0.216(t - t_0), & t_0 = 12 \\ 11.041 + 0.166(t - t_0), & t_0 = 24 \\ 12.874 + 0.104(t - t_0), & t_0 = 36 \\ 14.457 + 0.097(t - t_0), & t_0 = 48 \end{cases} \quad t \in (t_0 - 1.81, t_0 + 1.81) \quad (9)$$

For girl:  
$$ \hat{y} = \begin{cases} 3.236 + 0.972(t - t_0), & t_0 = 0 \\ 7.053 + 0.320(t - t_0), & t_0 = 6 \\ 8.469 + 0.225(t - t_0), & t_0 = 12 \\ 10.554 + 0.176(t - t_0), & t_0 = 24 \\ 12.501 + 0.235(t - t_0), & t_0 = 36 \\ 14.029 + 0.061(t - t_0), & t_0 = 48 \end{cases} \quad t \in (t_0 - 1.13, t_0 + 1.13) \quad (10)$$

Based on (9) and (10), the highest rate of weight growth is show at around one year old and then it is decreased with age. Plot of estimation of median ($P_{50}$) growth curve of weight for both boy and girl is showed as in Figure 1.

Figure 1. Plot of estimation of median ($P_{50}$) growth curve of weight for boy and girl

To assess nutritional status of children, we estimate the local linear standard growth charts at $P_3, P_{15}, P_{50}, P_{85},$ and $P_{97}$ based on optimal bandwidth showed in Table 1. The local linear standard growth charts for boy and girl are given together in the following Figure 2.
Figure 2. Local linear standard growth charts of weight for both boy and girl.

By comparing between the median (P50) growth charts of weight for both boy and girl in East Java, Indonesia and the median chart of WHO-2005 standard, we get that median growth charts of weight for both boy and girl in East Java, Indonesia are lower than WHO-2005 standard charts as shown in Figure 3.

Figure 3. Comparison between local linear median growth charts and WHO-2005 median growth charts of weight for both boy and girl.

The assessing of nutritional status of children up to five years old in East Java, Indonesia based on local linear standard growth charts and WHO-2005 standard charts applied to 18,961 boys and 17,962 girls are given in Table 2 as follows:

Table 2. Comparison of nutritional status between local growth charts and WHO-2005 standard charts

| Sex   | Nutritional Status | Local Linear Growth Charts | WHO-2005 Growth Standard Charts |
|-------|--------------------|-----------------------------|---------------------------------|
| Boy   | Overweight         | 15.61%                      | 6.13%                           |
|       | Normal             | 69.32%                      | 54.68%                          |
|       | Underweight        | 15.07%                      | 39.19%                          |
| Girl  | Overweight         | 15.32%                      | 7.10%                           |
|       | Normal             | 69.97%                      | 57.51%                          |
|       | Underweight        | 14.71%                      | 35.39%                          |

According to Table 2, the percentage of nutritional status, i.e., underweight, children up to five years old in East Java, Indonesia for both boy and girl based on local linear growth charts are less than those based on WHO-2005 standard growth charts. In general, the local linear standard growth charts of weight for both boy and girl have the evaluator standard which are lower than the standard charts of WHO-2005. This condition occurs because the samples used to design the local linear standard growth charts, i.e., children up to five years old in East Java, physically have characteristics that different from samples used to design the WHO 2005 standard charts, i.e., Brazil, Ghana, India, Norway, Oman and the United States. In addition, there are some children especially more than two years old in East Java, Indonesia have nutritional status, i.e., Normal based on local standard but based on WHO-2005 standard charts they have underweight nutritional status.

7. Conclusion
The estimation of standard growth chart for weight using local linear estimator of children in East Java, Indonesia is good estimation which has goodness of fit criterion, i.e., the coefficient of
determination ($R^2$) tends to one and mean square error (MSE) tends to zero. The median growth chart for weight of boy based on local linear estimator is lower than it of girl. In addition, the physical characteristics of children used to as sample to design the local linear standard growth charts are different from the children of Brazil, Ghana, India, Norway, Oman and the United States who were used to design WHO-2005 standard charts.

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