Original Article

Detecting Age Prone to Growth Retardation in Children Through a Bi-Response Nonparametric Regression Model with a Penalized Spline Estimator

Abstract

Background: The growth of children aged 0–60 months can impact their subsequent growth and development. This study aims to identify the vulnerable age for boys and girls, who experience growth retardation within this age range. **Methods:** The study design used was a cross-sectional approach in which each child's measurement data was only taken once. The data were obtained from weighing results at the Health Integrated Service Post in South Sulawesi Province in 2022. The number of data analyzed was 698 children, namely 369 boys and 329 girls by considering the factors of age, weight, and height. We used a nonparametric bi-response regression model estimated using a penalized spline. The knots used are 12, 24, 36, and 48 on each model. **Results:** The value of the penalized spline regression coefficient in the model indicates that the child's growth is slowed down and is not within normal limits. This can be seen in the weight and height of boys from the age of reaching 12 months to 24 months, only increasing by about 0.3 kg and 0.3 cm. For girls, the problem occurs from the age of 24 to 36 months, namely their weight increases by about 0.6 kg, and their height increases by about 1 cm. **Conclusions:** The analysis results show that boys' growth slows down at 2 years of age and continues until 5 years of age. In the case of girls, their growth begins to slow when they are 3 years old until they reach 5 years old.

Keywords: *Growth retardation, height, regression, weight*

Anna Islamiyati[1], Anisa Kalondeng[1], Muhammad Zakir[2], Sultan Djibe[3], Ummi Sari[4]

[1]Department of Statistics, Hasanuddin University, Makassar, Indonesia, [2]Department of Mathematics, Hasanuddin University, Makassar, Indonesia, [3]Department of Sociology, Hasanuddin University, Makassar, Indonesia, [4]Teching Hospital, Hasanuddin University, Makassar, Indonesia

Address for correspondence:
Dr. Anna Islamiyati, Jl. Politeknik No. 701 Tamalanrea, Makassar, Propinsi Sulawesi Selatan, Indonesia. E-mail: annaislamiyati701@gmail.com

Introduction

In the problem of child growth, mothers need to focus on the age group of 0–60 months for their children. Some studies have indicated that the World Health Organization (WHO) standard health card may not be universally applicable, as there are variations in the condition of children across different regions.[1] These differences could be attributed to varying geographical conditions.[2] Some studies have suggested that child growth and developmental, issues can be influenced by factors such as nutritional intake,[3] economic status,[4] and social determinants of health.[5] The nutritional status of children has been extensively researched, with findings indicating that boys are more prone to malnutrition compared to girls, particularly before they reach 5 years of age.[6]

To obtain accurate analysis results, a flexible statistical approach is needed to be able to analyze the condition of each child at every age of growth. We propose the use of nonparametric spline regression, which is a flexible statistical approach because the data itself will search for appropriate data patterns.[7] Spline involves knot points in its function to ensure its flexibility in forming segmentation patterns from changes that occur in the data.[8] Therefore, this model is very well used in analyzing health data, which usually have a variety of patterns. Specifically, in this study, the model is used to detect the pattern of growth and development of children at each age interval. The tendency of a pattern of changes that occur in the child's growth and development will be shown based on the optimal placement of knot points. Several types of splines can be used, namely, spline truncated[9] and smoothing spline.[10] In large variable dimensions, the approaches that have been used include mixed smoothing spline and Fourier series,[11] spline in

How to cite this article: Islamiyati A, Kalondeng A, Zakir M, Djibe S, Sari U. Detecting age prone to growth retardation in children through a Bi-response nonparametric regression model with a penalized spline estimator. Iran J Nurs Midwifery Res 2024;29:549-54.

Submitted: 06-Nov-2022. **Revised:** 21-May-2024. **Accepted:** 03-Jun-2024. **Published:** 04-Sep-2024.

Access this article online

Website: https://journals.lww.com/jnmr

DOI: 10.4103/ijnmr.ijnmr_342_22

Quick Response Code:

multi-response cases,[12] spline bi-predictors,[13] and PCA spline.[14]

We use a penalized spline estimator, a form of spline estimator that involves the goodness of fit function and the penalty function in the estimation criteria. This is based on previous studies that the penalized spline estimator in nonparametric regression has accurate analysis results owing to the involvement of knot points and smoothing parameters.[15] If the data contains two responses and are correlated with each other, then we use a bi-response nonparametric regression model.[16] For this reason, we detected the age at which children are susceptible to developmental delays through a penalized spline bi-response model. This study aims to determine the age at which children begin to experience slowed growth based on the factors of weight and height between the ages of 0 and 60 months. Both weight and height are assumed to be correlated with each other, so they must be analyzed together. We detect it in the weight and height factors of children aged 0–60 months, both of which are assumed to be correlated with each other so they must be analyzed together.

Materials and Methods

In this study, we utilized a cross-sectional approach to analyze weight and height data as indicators of children's growth based on their age in months. This study began in 2022 when children's weight and height were measured during visits to several Health Integrated Service Post (Posyandu) centers. Digital weighing devices and stadiometers were used to obtain accurate measurements. The measurements align with WHO standards for assessing children's growth and nutritional status.[17] Data on weight and height were collected during a single measurement session at various Posyandu centers in South Sulawesi province in 2022. Posyandu centers in Indonesia are local health facilities that offer maternal and child health services. Reporting to the main center occurs every six months. The analysis included data from 698 children aged 0–60 months, with 369 boys and 329 girls, considering their age (months), weight (kg), and height (cm). The sample consisted of all children who attended routine weighing sessions at Posyandu centers in the research area of South Sulawesi Province.

We developed a nonparametric regression model with two responses and only one predictor. The first response, second response, and predictor are represented by the child's weight, child's height, and age factor. The analysis is conducted separately for each gender. The growth of both weight and height in boys and girls is analyzed based on the child's age interval in months. It can be shown through nonparametric regression with a penalized spline that considers knot points and smoothing parameters. Knots are points where changes occur, while smoothing parameters are values that play a role in obtaining a smoother regression curve and are denoted by λ.

The data on child growth were analyzed by segmenting the child's age into 5 intervals, 0–12, 13–24, 25–36, 37–48, and 49–60. These intervals correspond to the determination of knot points on the age factor, which are 4 knot points, 12, 24, 36, and 48. Each knot point will have a regression coefficient indicating the changes that occur in each segmentation. In this study, there are 5 regression parameters estimated, namely β_1 as the regression coefficient when the child reaches the age of 12 months, β_2 for 12 to 24 months, β_3 for 24 to 36 months, β_4 for 36 to 48 months, and β_5 when the child reaches the age of over 48 months. These smoothing parameters work together with knot points to create an optimal model based on the minimum value of the generalized cross validation (GCV) value.[18] The data analysis is conducted using the open-source R software.

Ethical considerations

The ethical approval for this research was obtained through a letter of introduction with reference number 8296/UN4.11/HM.01.01/02/2022. With the official decree, the research team was granted permission to access and retrieve data from the Posyandu.

Results

The data analyzed in this study pertains to the growth of children based on their sex. Weight and height were two key factors monitored to assess the nutritional status of children under five years of age. The average weight and height measurements at the ages of 12, 24, 36, 48, and 60 months for a total of 698 children, comprising 369 boys and 329 girls, are displayed in Figure 1. The boxplots illustrate the distribution of the child's weight and height data, while the growth values standardized the WHO are depicted by black lines. Variations in the growth of boys and girls within each age group are evident, highlighting the importance of analyzing. The growth and development of children based on their sex. This approach, adopted by WHO and numerous researchers, enables a more nuanced examination of child development.[17]

The plot in Figure 2 displayed the growth of children aged 0–60 months, with varying data distribution for each sex. To analyze this data, a nonparametric bi-response regression approach was utilized, employing a penalized spline estimator with 4-knot points positioned at points 12, 24, 36, and 48 months, along with the appropriate smoothing parameters. The objective of this analysis was to detect any changes in patterns that occurred at each age interval in the growth trajectories.

Furthermore, the optimal smoothing parameters determined through the penalty spline estimation criteria were obtained through an iterative process. The estimation results for each specific smoothing parameter value yielded different

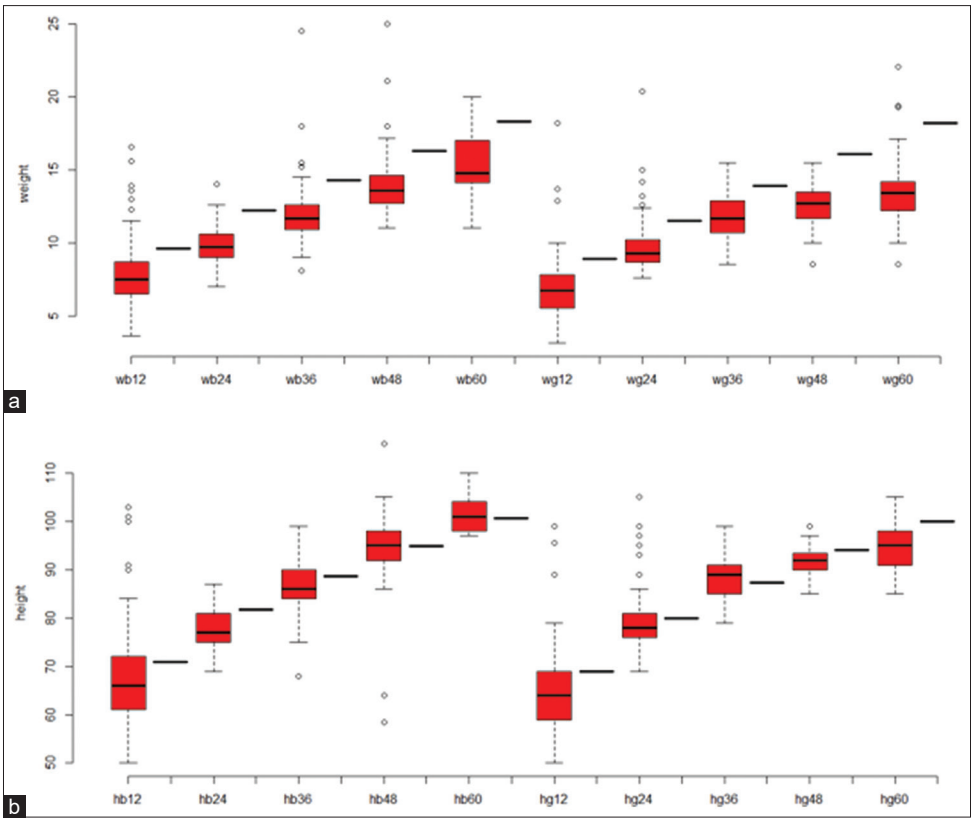

Figure 1: Box plot of children's growth values (a) weight and (b) height with WHO standard values

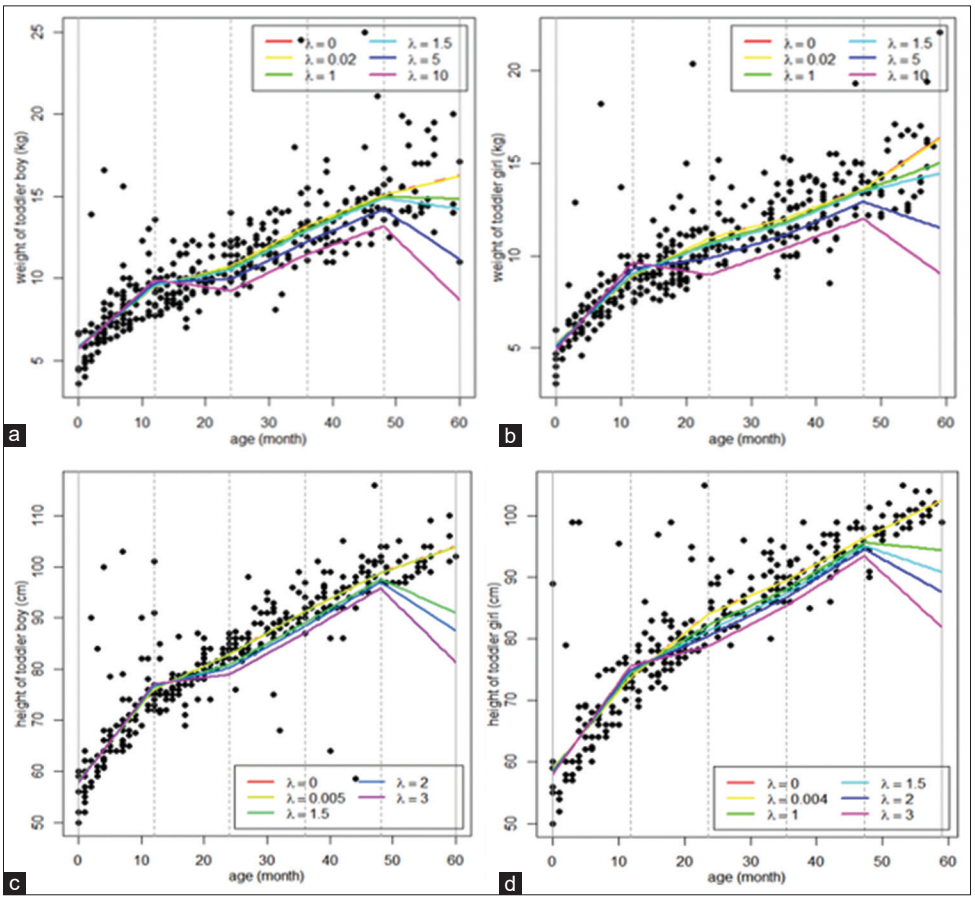

Figure 2: Regression curves on several smoothing parameters for estimating growth in weight (a) boys, (b) girls, and height (c) boys, (d) girls

regression curves as depicted in Figure 2. The minimum GCV value for the smoothing parameter was indicated by the yellow regression curve shown in Figure 2 (a)-(d). The smoothing parameter value for the weight growth model was the same for boys and girls at 0.02. Furthermore, for the height growth model, the smoothing parameter was 0.005 for boys and 0.004 for girls. These outcomes suggest that the yellow regression curve is the optimal choice for analyzing the growth of children aged 0–5 years.

Figure 3 displays the regression curve that was obtained by fitting the nonparametric bi-response regression model using the penalized spline estimator. The curve was determined based on the optimal smoothing parameter that minimized the GCV value. The regression coefficient values in Table 1 for children's weight growth, and Table 2 for children's height growth provide key information on how age impacts these growth parameters in children. Because of the analysis and the regression curve in Figure 3(a), weight growth in boys shows a noticeable slowdown as age reaches around 2 years. After this point, there is an increase in growth, but it does not align with the standard size of normal weight for a child of that age. The estimated increase in weight and height as shown in Table 1 provides important insights into the growth patterns of children based on the model. According to the estimate,

Table 1: Estimation of the regression coefficient of the growth model of boys

Age (month)	Weight of boys		Height of boys	
	Normal Weight	Coefficient (β_{1wb}- β_{5wb}) for λ=0.02	Normal Height	Coefficient (β_{1hg}- β_{5hg}) for λ=0.005
0-12	9.60 – 12.20kg	9.67	71.00 – 80.50 cm	77.38
13-24	12.20 – 14.30 kg	10.00	81.70 – 93.90 cm	77.73
25-36	14.30 – 16.30 kg	12.01	88.70 – 103.50 cm	85.86
37-48	16.30 – 18.30 kg	14.40	94.90 – 111.70 cm	94.51
49-60	18.30 – 24.20 kg	11.86	100.70 – 119.20 cm	76.04

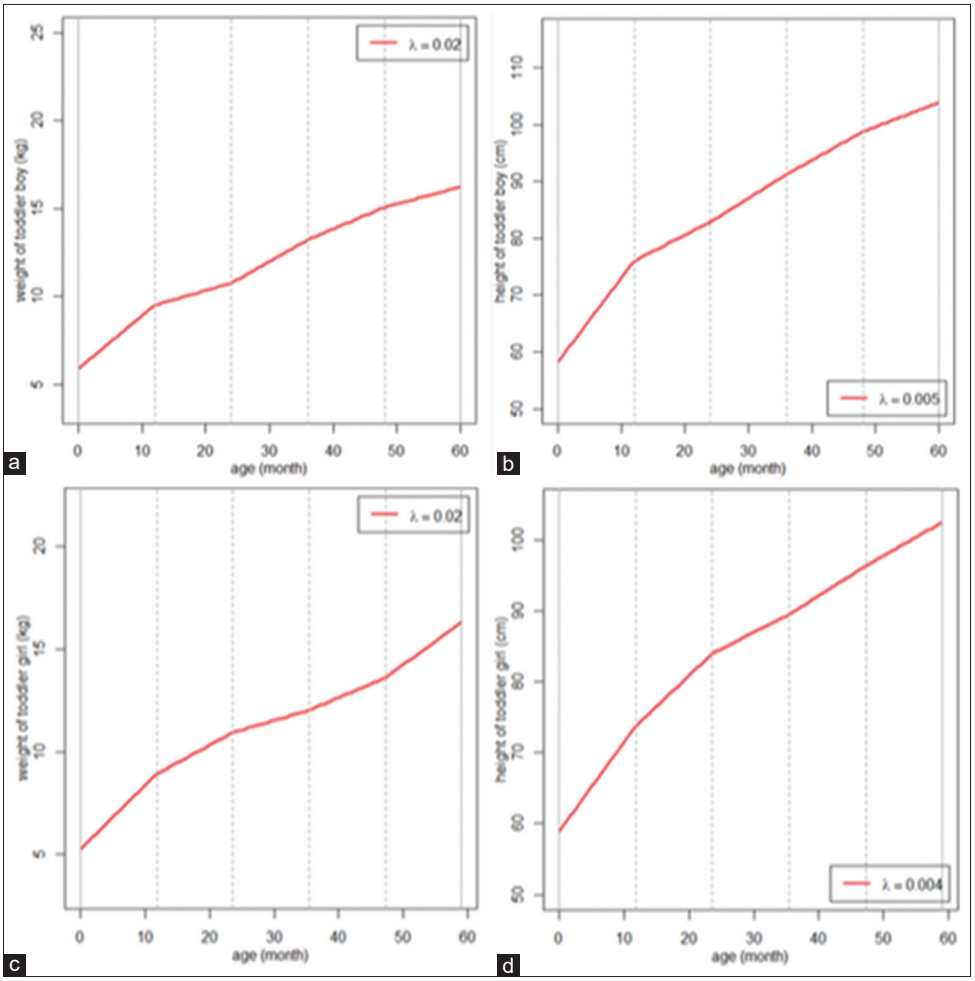

Figure 3: Estimation of growth curves for (a) boy's weight, (b) boy's height, (c) girl's weight, and (d) girl's height using a penalized spline bi-response regression model

Table 2: Estimation of the regression coefficient of the growth model of girls

Age (month)	Weight of girls		Height of girls	
	Normal Weight	Coefficient (β_{1wb} - β_{5wb}) for λ=0.02	Normal height	Coefficient (β_{1hg} - β_{5hg}) for λ=0.004
0-12	8.90 – 11.50 kg	9.23	68.90 – 79.20 cm	76.21
13-24	11.50 – 13.90 kg	11.60	80.00 – 92.90 cm	80.19
25-36	13.90 – 16.10 kg	12.12	87.40 – 101.70 cm	81.16
37-48	16.10 – 18.20 kg	13.10	94.10 – 111.30 cm	92.20
49-60	18.20 – 24.00 kg	12.19	99.90 – 118.90 cm	76.91

the weight of boys up to 1 year of age remains within normal limits, approximately around 9.67 kg compared to the normal standard of 9.60 kg. However, as boys reach the age of 2 years, their weight increases very slowly, reaching 10 kg, which is below the normal range of 12.20–14.30 kg. The estimated values of the penalized spline bi-response regression parameters for boys' height correspond to the height growth curve depicted in Figure 3(b). The analysis shows that boys experience rapid growth in height by the age of 1 year, reaching approximately 77.38 cm. However, this growth appears to slow down by the age of 2 years, with an estimated height of about 77.73 cm, falling below the normal standard range for a healthy child (81.70–93.90 cm). This suggests that the increase in height at this age is only about 0.35 compared to the previous year's height. Overall, the findings indicate a deceleration in growth for both weight and height at around 2 years of age.

The weight growth curve for girls shown in Figure 3(c) shows that up to the age of 2 years, the weight of girls remains within the normal range based on the estimated values of the penalized spline regression coefficients in Table 2. However, there is a noticeable slowdown in weight growth once girls reach the age of 3 years, with a body weight of 12.12 kg falling below the normal standard of 13.90–16.10 kg. This suggests that the weight growth of girls starts to decelerate around the age of 3 years, indicating a potential vulnerability or slowdown in growth during this period. In Figure 3(d), girls exhibit a more stable height compared to boys, as indicated by the shape of the growth curves. The estimated height growth values in Table 2 show that from the age of 1 to 2 years, the height of girls remains within normal limits. However, a notable decrease in growth rate is observed as girls reach the age of 3 years, with a height of 81.16 cm falling below the normal range of 87.40–101.70 cm. The increase in height at this age is minimal, only about 1 cm compared to the previous age. These findings suggest that the age of 3 years may be a critical period for girls in terms of experiencing delays in weight and height growth.

Discussion

The analysis of children growth aged 0–60 months (0–5 years) in South Sulawesi Province, Indonesia, using a nonparametric bi-response regression model with a penalized spline estimator has provided valuable insights into the growth patterns of boys and girls over time. The data collected, measuring weight and height monthly, revealed that both boys and girls show an increase in weight and height with age. However, distinct differences were observed in the growth patterns between boys and girls. The growth of girls from 0 to 5 years was found to be more stable compared to boys, as indicated by the results of the estimated growth curve showing a gentler slope for boys as opposed to girls. These findings are consistent with previous studies that have reported differences in growth patterns between boys and girls, with boys being more likely to experience malnutrition compared to girls, particularly before the age of 5 years.[6,19]

The analysis of children aged 0 to 5 years has highlighted age ranges that are prone to slower growth in weight and height. In boys, the vulnerable age for growth concerns was identified as 2 years old, while in girls, this age was observed to be 3 years. This suggests that boys may be more likely to experience growth issues compared to girls, despite having higher average weight and height during the first year of life. The condition appears to be consistent across various regions. Consequently, they are more susceptible to conditions such as malnutrition,[20] stunting,[21] and other growth problems. In a study conducted in rural Ellisra, South Africa, girls grow faster in height than boys.[22] In the South Asian region, malnutrition is commonly found in boys under 5 years old is also common in boys.[6] Despite boys typically being larger at birth and during infancy, they are more prone to infectious diseases and have weaker immune systems than girls.[23] The results of this study suggest that growth patterns for boys in Indonesia align with those observed in other countries, indicating that their growth tends to be slower than that of girls. Therefore, parents should pay particular attention to the growth of 2-year-old boys and 3-year-old girls to prevent any slowdown in growth. Early detection and intervention in addressing growth issues in children can significantly impact their long-term health and development. This study only shows the age at which children begin to experience slowed growth. For further research, it is necessary to examine how social, economic, and demographic factors influence the child's growth and development.

Conclusion

The results of this study indicate that growth slowdown in boys, both in weight and height, commences at the age of

2 years and 3 years for girls. Despite of boys having higher weight and height at birth, their growth is not as rapid as that of girls. Parents should remain attentive to their child's growth from birth until the age of 5 years. They should not assume that a healthy body condition during the first year of their child's life ensures continual good growth. Future research should focus on examining how local wisdom in various regions, including social, cultural, and economic aspects, can impact childcare practices.

Acknowledgments

Thank you to the Health Service Paysandú officers in several areas in South Sulawesi Province, Indonesia.

Key messages

Growth model of height; growth model of weight; growth retardation; penalized spline.

Financial support and sponsorship

This work was funded by a National Competitive Basic Research grant from the Directorate of Research, Technology, and Community Service, Directorate General of Higher Education, Research and Technology of the Ministry of Education, Culture, Research, and Technology with research contract No: 01676/UN4.22/PT.01.03/2023 dated April 14, 2023.

Conflicts of interest

There are no conflicts of interest.

References

1. Chamidah N, Saifudin T. Designing local standard growth charts of children in East Java province using a local linear estimator. Int J Innov Create Change 2020;13:45–67.
2. Pulungan AB, Julia M, Barubara JR, Hermanussen M. Indonesian national synthetic growth charts. Acta Sci Paediatr 2018;1:1–15.
3. Moro C, Covino J. Nutrition and growth: Assessing the impact of regional nutritional intake on childhood development and metacarpal parameters. Anat Cell Biol 2018;51:31–40.
4. Poulain T, Vogel M, Sobek C, Hilbert A, Körner A, Kiess W. Associations between socio-economic status and child health: Findings of a large German cohort study. Int J Environ Res Public Health 2019;16:1–12.
5. Atashbahar O, Sari AA, Takian A, Olyaeemanesh A, Mohamadi E, Barakati SH. The impact of social determinants of health on early childhood development: A qualitative context analysis in Iran. BMC Public Health 2022;22:1–13.
6. Thurstans S, Opondo C, Seal A, Wells J, Khara T, Dolan C, *et al*. Boys are more likely to be undernourished than girls: A systematic review and meta-analysis of sex differences in undernutrition. BMJ Glob Health 2020;5:1–17.
7. Hidayat R, Budiantara IN, Otok BW, Ratnasari V. The regression curve estimation by using mixed smoothing spline and kernel (MsS-K) modeltle. Commun Stat-Theor M 2021;50:3942–53.
8. Islamiyati A, Fatmawati, Chamidah N. Changes in blood glucose 2 hours after meals in type 2 diabetes patients based on length of treatment at Hasanuddin University Hospital, Indonesia. Rawal Med J 2020;45:31–4.
9. Islamiyati A, Raupong, Kalondeng A, Sari U. Estimating the confidence interval of the regression coefficient of the blood sugar model through a multivariable linear spline with known variance. Stat Transit 2022;23:201–12.
10. Lestari B, Fatmawati, Budiantara IN, Chamidah N. Smoothing parameter selection method for multiresponse nonparametric regression model using smoothing spline and Kernel estimators approaches. J Phys Conf Ser 2019;1397:1-8.
11. Mariati NPAM, Budiantara IN, Ratnasari V. The application of mixed smoothing spline and fourier series model in nonparametric regression. Symmetry (Basel) 2021;13:1-22.
12. Islamiyati A. Spline longitudinal multi-response model for the detection of lifestyle-based changes in blood glucose of diabetic patients. Curr Diabetes Rev 2022;18:98–104.
13. Islamiyati A, Sunusi N, Kalondeng A, Fatmawati F, Chamidah N. Use of two smoothing parameters in penalized spline estimator for bi-variate predictor non-parametric regression model. J Sci Islam Repub Iran 2020;31:175–83.
14. Islamiyati A, Kalondeng A, Sunusi N, Zakir M, Amir AK. Biresponse nonparametric regression model in principal component analysis with truncated spline estimator. J King Saud Univ Sci 2022;34:1–9.
15. Islamiyati A, Fatmawati, Chamidah N. Estimation of covariance matrix on bi-response longitudinal data analysis with penalized spline regression. J Phys Conf Ser 2018;979:1–7.
16. Islamiyati A, Fatmawati, Chamidah N. Penalized spline estimator with multi smoothing parameters in bi-response multi-predictor nonparametric regression model for longitudinal data. Songklanakarin J Sci Technol 2020;42:897–909.
17. Costa JC, Blumenberg C, Victora C. Growth patterns by sex and age among under-5 children from 87 low-income and middle-income countries. BMJ Glob Health 2021;6:1–10.
18. Chamidah N, Lestari B, Massaid A, Saifudin T. Estimating mean arterial pressure affected by stress scores using spline nonparametric regression model approach. Commun Math Biol Neurosci 2020;2020:1–12.
19. Gharpure R, Mor SM, Viney M, Hodobo T, Lello J, Siwila J, *et al*. A one health approach to child stunting: Evidence and research agenda. Am J Trop Med Hyg 2021;104:1620-4.
20. Samuel A, Osendarp SJM, Feskens EJM, Lelisa A, Adish A, Kebede A, *et al*. Gender differences in nutritional status and determinants among infants (6–11 m): A cross-sectional study in two regions in Ethiopia. BMC Public Health 2022;22:1–12.
21. Laksono AD, Wulandari RD, Amaliah N, Wisnuwardani RW. Stunting among children under two years in Indonesia: Does maternal education matter? PLoS One 2022;17:1–11.
22. Nembidzane C, Lesaoana M, Monyeki KD, Boateng A, Makgae PJ. Using the sitar method to estimate age at peak height velocity of children in rural south africa: Ellisras longitudinal study. Children (Basel) 2020;7:1-9.
23. Thurstans S, Opondo C, Seal A, Wells JC, Khara T, Dolan C, *et al*. Understanding sex differences in childhood undernutrition: A narrative review. Nutrients 2022;14:1–15.