BAREKENG: Journal of Mathematics and Its Applications
December 2025 Volume 19 Issue 4 Page 2347–2358
P-ISSN: 1978-7227 E-ISSN: 2615-3017
https://doi.org/10.30598/barekengvol19iss4pp2347-2358

MODELING DEMOCRACY INDEX IN INDONESIA WITH MULTIVARIATE ADAPTIVE REGRESSION SPLINE APPROACH

Toha Saifudin[1], **Suliyanto**[2], **Galuh Cahya Nugraha**[3*], **Hanny Valida**[4], **Muhammad Hafidzuddin Nahar**[5], **Regina Fortunata**[6]

[1,2,3,4,5,6]*Statistics Study Program, Faculty of Science and Technology, Universitas Airlangga*
Jln. Dr. Ir. H. Soekarno, Mulyorejo, Surabaya, 60115, Indonesia

*Corresponding author's e-mail: * **galuh.cahya.nugraha-2022@fst.unair.ac.id***

Article History:

Received: 10th December 2024
Revised: 18th February 2025
Accepted: 27th June 2025
Available online: 1st September 2025

Keywords:

Democracy Index;
MARS;
Nonparametric Regression;
SDG 16

ABSTRACT

Democracy is a system of government where citizens participate in political decision-making through freely elected representatives. To measure the quality of democracy in Indonesia, the Indonesian Democracy Index (IDI) is used as a composite indicator reflecting various aspects of political freedoms, civil liberties, and governance. The IDI score declined from 6.71 in 2022 to 6.53 in 2023, the lowest in 14 years, indicating disruption in Indonesia's democracy. Therefore, it is necessary to identify the root causes of the disruption in Indonesia's democracy through several indicators. This study analyzes the relationship between predictor variables, including socio-economic and development indicators, and IDI using the Multivariate Adaptive Regression Spline (MARS) approach. This study uses the MARS method by considering six predictor variables, namely the Human Development Index (HDI), Gender Empowerment Index (GEI), Information and Communication Technology Development Index (ICT-DI), Press Freedom Index (PFI), Poverty Depth Index (PDI), and High School Completion Rate (HSCR). The data used is secondary data from 34 Indonesian provinces in 2023 obtained from the Statistics Indonesia-BPS. The results showed that the best model was obtained with a combination of BF = 12, MI = 3, and MO = 1 resulting in a GCV value of 11.27 and R^2 of 80%. MARS model interpretation identifies the significant influence of social and economic indicators on IDI and is able to explain 80% of data variability. The significance test shows that all predictor variables significantly affect the IDI, with the highest level of importance on the ICT-DI variable. Therefore, improving ICT-DI in each province needs to be a major concern as a strategic step to improve the democracy index in Indonesia and support the achievement of Sustainable Development Goal 16 on peace, justice, and strong institutions.

How to cite this article:

T. Saifudin, Suliyanto, G. C. Nugraha, H. Valida, M. H. Nahar and R. Fortunata, "MODELING DEMOCRACY INDEX IN INDONESIA WITH MULTIVARIATE ADAPTIVE REGRESSION SPLINE APPROACH," *BAREKENG: J. Math. & App.*, vol. 19, no. 4, pp. 2347-2358, December, 2025.

Journal homepage: *https://ojs3.unpatti.ac.id/index.php/barekeng/*
Journal e-mail: *barekeng.math@yahoo.com; barekeng.journal@mail.unpatti.ac.id*

Research Article · Open Access

1. INTRODUCTION

According to the International Commission for Jurists, democracy is a system of government in which citizens make political decisions through representatives they elect and who are accountable to them through free elections [1]. To assess the quality of democracy in Indonesia, the government uses the Indonesian Democracy Index (IDI) as a tool to measure achievements and plan political development [2].

Reporting from DW.com, Indonesia is ranked 64th in the world in the democracy index released by the Economist Intelligence Unit (EIU) with a score of 6.3 [3]. Although Indonesia's ranking remains the same as in 2020, its score has decreased from the previous 6.48. This is the lowest score Indonesia has achieved in the last 14 years, indicating that the country can be categorized as having a flawed democracy. Furthermore, EIU noted that Indonesia's democracy index score decreased from 6.71 in 2022 to 6.53 in 2023, indicating a breakdown in Indonesia's democracy [4]. An understanding of democracy is essential because democracy teaches that the people are the main resource who have the awareness to create rules that protect their rights. Therefore, rules must be established to support and serve as the foundation of state life, ensuring and protecting the people's rights [5]. The IDI is related to Sustainable Development Goals (SDGs) point 16 which focuses on peace, justice and strong institutions. The SDGs aim to strengthen inclusive and peaceful societies, provide access to justice for all, and build effective and accountable institutions. By strengthening institutions and ensuring equitable access to justice, Indonesia can improve the quality of its democracy, which will drive sustainable and inclusive development. Therefore, achieving SDGs point 16 is crucial for political and social development in Indonesia, as well as ensuring democracy functions optimally for the welfare of the people.

Factors that influence the IDI include economic, social, and technological aspects. The Human Development Index (HDI) is also an important indicator to measure the physical and non-physical quality of the population and development outcomes in each region [6]. The combined influence of these factors shows that sustainable and inclusive development plays a significant role in promoting healthy democracy in a region. Another factor affecting the IDI is the role of gender equality. This is because equality between genders affects "Substantive Democracy" which is another term for ideal democracy [7]. The Gender Empowerment Index (GEI) reflects the extent of women's active role in the economic and political spheres in Indonesia. This role includes participation in politics, involvement in the economy, as well as decision-making and control of economic resources. The GEI is basically used to assess the extent to which women's capabilities are utilized in various sectors of life. In addition, the GEI also serves to measure the equality of roles between men and women in decision-making, both in politics and in the managerial field, and how this equality supports the strengthening of democracy in Indonesia.

In addition, another factor that affects the development of democracy is the level of progress in information and communication technology, which is reflected through the Information and Communication Technology Development Index (ICT-DI). The success of a democratic system in certain situations is greatly influenced by technology, where information and communication technology play a crucial role in disseminating political news, which is one of the basic rights of every citizen. In addition, computing technology is also used in the vote-counting process during elections [8]. Similarly, the Press Freedom Index (PFI) has an important role in improving the quality of democracy in Indonesia. A free press allows the media to carry out its oversight function of the government and provide accurate and transparent information to the public. With press freedom, the public can access diverse information to make independent political decisions, assess government performance and hold leaders accountable. This supports the realization of a higher quality democracy [9].

The Poverty Depth Index (PDI) plays an important role in influencing democracy in Indonesia. Increased poverty can hinder democracy through two aspects. First, better welfare and access to education support democratization by providing adequate information and opportunities. Second, vulnerable economic conditions can trigger instability and potential repressive measures, which risk leading to authoritarianism. Therefore, poverty alleviation oriented towards economic prosperity and justice is necessary to strengthen democracy [10]. Additionally, high school completion rates (HSCR) play an important role in improving the quality of democracy in Indonesia. Senior secondary education broadens people's political horizons and hones their critical thinking skills, enabling them to be more aware of political rights and responsibilities. With this knowledge, individuals are more active in political activities such as elections and policy discussions. The participation of these educated citizens promotes transparency and accountability of leaders, which ultimately supports the improvement of democratic quality [11].

Many studies on IDI have been conducted, one of which is by Ramdhani [12] who examines the effect of exchange rates, inflation, and interest rates on IDI using multiple regression methods with various relationship assumptions. The results showed that the rupiah exchange rate has a significant positive effect on the IDI. However, this study is limited to the economic aspect, whereas the IDI is influenced by various other more complex factors, such as political, social, and technological.

To understand the relationship of the factors affecting the democracy index in Indonesia, the regression analysis method is used. Regression analysis is a statistical technique used to identify the relationship pattern between response variables (Y) and predictor variables (X). Its primary goal is to estimate the form of the regression curve. This regression curve estimation can be done with parametric or nonparametric approaches [13]. One of the nonparametric regression models used is Multivariate Adaptive Regression Spline (MARS), which is applied when the shape of the relationship between response and predictor variables is unknown. This method does not assume a certain form of relationship (such as linear, quadratic, or cubic) between the response variable and its predictors [14]. MARS is more focused on handling problems with high dimensions, large samples, and many variables, thus requiring complex calculations with the smallest Generalized Cross Validation (GCV) value [15]. This approach is considered more effective in modeling interactions between variables, especially in the context of IDI, which is influenced by various aspects and factors.

This research has an advantage because there has been no research that discusses the Indonesian Democracy Index with the MARS method before. Therefore, to make a new contribution, this study uses the MARS model with six predictor variables, namely HDI, GEI, ICT-DI, PFI, PDI, HSCR in modeling the IDI. This method is also able to provide comprehensive and flexible results in analyzing the interaction between predictor variables. Not only that, this research also aims to identify the variables that have the most influence on the IDI and its impact on the democracy index in Indonesia, so that it can be used as a basis for the government in making policies.

2. RESEARCH METHODS

The data used in this study are secondary data sourced from the official website of the Statistics Indonesia-BPS related to the democracy index of each province in Indonesia in 2023. The variables in this study are divided into predictor variables ($\boldsymbol{X}$) and response variables ($\boldsymbol{Y}$) with details in **Table 1** as follows.

Table 1. Research Variables

Variable	Variable Name	Acronym	Scale
Y	Indonesian Democracy Index	IDI	Ratio
X_1	Human Development Index	HDI	Ratio
X_2	Gender Empowerment Index	GEI	Ratio
X_3	Information and Communication Technology Development Index	ICT-DI	Ratio
X_4	Press Freedom Index	PFI	Ratio
X_5	Poverty Depth Index	PDI	Ratio
X_6	High School Completion Rate	HSCR	Ratio

The analysis method used to model the democracy index in Indonesia in this study is MARS modeling. The MARS method was chosen because it is one of the nonparametric regression models that can be used when the shape of the relationship function between the response variable and the predictor variable is unknown [16]. The general form of the MARS model is given in **Equation (1)** as follows [17].

$$\boldsymbol{f(x) = a_0 + \sum_{m=1}^{M} a_m \prod_{k=1}^{K_m} \left[s_{km} \times \left(x_{v(k,m)} - t_{km} \right) \right]} \quad (1)$$

With:

$\boldsymbol{a_0}$: parent base function coefficient
$\boldsymbol{a_m}$: $\boldsymbol{m^{th}}$ base function coefficient

$\boldsymbol{M}$: number of the maximum base function
$\boldsymbol{K_m}$: maximum degree of interaction at $\boldsymbol{m^{th}}$ base function
$\boldsymbol{s_{km}}$: is 1 if $\boldsymbol{x}$ is located to the right of the knot point and is (-1) if $\boldsymbol{x}$ is located to the left of the knot point.
$\boldsymbol{x_{v(k,m)}}$: $\boldsymbol{v^{th}}$ predictor variable
$\boldsymbol{t_{km}}$: knot value of the predictor variable

Based on the nonparametric regression function, the MARS model is expressed in the in **Equation (2)** as follows.

$$\boldsymbol{y_i = a_0 + \sum_{m=1}^{M} a_m \prod_{k=1}^{K_m} [s_{km} \times (x_{p_n(k,m)} - t_{km})] + \varepsilon_i} \tag{2}$$

From the MARS model **Equation (2)** in matrix form can be written as follows.

$$\boldsymbol{Y = Ba + \varepsilon} \tag{3}$$

with:

$Y = (y_1, y_2, \dots, y_n)^T$

$a = (a_0, a_1, \dots, a_M)^T$

$$B = \begin{pmatrix} 1 & \prod_{k=1}^{K_1}[s_{1m} \times (x_{v_1(1,m)} - t_{1m})] & \cdots & \prod_{k=1}^{K_M}[s_{Mm} \times (x_{v_1(M,m)} - t_{Mm})] \\ 1 & \prod_{k=1}^{K_1}[s_{1m} \times (x_{v_2(1,m)} - t_{1m})] & \cdots & \prod_{k=1}^{K_M}[s_{Mm} \times (x_{v_2(M,m)} - t_{Mm})] \\ \vdots & \vdots & \ddots & \vdots \\ 1 & \prod_{k=1}^{K_1}[s_{1m} \times (x_{v_n(1,m)} - t_{1m})] & \cdots & \prod_{k=1}^{K_M}[s_{Mm} \times (x_{v_n(M,m)} - t_{Mm})] \end{pmatrix}$$

While the model estimation is obtained from **Equation (3)**, which is as follows.

$$\boldsymbol{\hat{Y} = B\hat{a}} \tag{4}$$

To estimate the parameter $\boldsymbol{\hat{a}}$, the Least Square estimation method is used as follows.

$$\boldsymbol{\hat{a} = (B^T B)^{-1} B^T Y} \tag{5}$$

Therefore, by substituting **Equation (5)** into **Equation (4)**, **Equation (6)** is obtained as follows.

$$\boldsymbol{\hat{Y} = B(B^T B)^{-1} B^T Y} \tag{6}$$

The stages of data analysis in this study were carried out with the following steps.

1. Collecting research data related to the democracy index in Indonesia.
2. Analyzing the characteristics of the research variables descriptively.
3. Determining the Base Function (BF) values at 12, 18, and 24, based on six predictor variables, assuming 2, 3, and 4 basis functions per variable. Maximum Interaction (MI) values were set at 1, 2, and 3, and Minimum Observation (MO) values at 0, 1, 2, and 3.
4. Combining the values of BF, MI, MO to get the best MARS model.

   The selection of the best MARS model is based on the smallest GCV value, followed by comparing the Mean Square Error (MSE) value and the coefficient of determination ($\boldsymbol{R^2}$) if there is the same value **[17]**. GCV calculation can be done using **Equation (7)** as follows.

$$\boldsymbol{GCV(M) = \frac{\frac{1}{n}\sum_{i=1}^{n}[y_i - \hat{f}_M(x_i)]^2}{\left[1 - \frac{\hat{C}(M)}{n}\right]^2}} \tag{7}$$

with:

y_i : response variable
x_i : predictor variable
n : number of samples
$\hat{f}_M(x_i)$: the estimated value of the response variable on M base functions at x_i
M : maximum number of base functions
$\hat{C}(M)$: $C(M) + d.M$
$C(M)$: $Trace\left[B\left(B^T B\right)^{-1} B^T\right] + 1$
B : matrix of M base functions
d : the value when each base function achieves optimization ($2 \leq d \leq 4$)

5. Test all base function coefficients simultaneously using the F test statistic or Fisher Test [18]. The hypothesis employed for simultaneous testing of the base function coefficients is as follows.

 H_0 : $a_1 = a_2 = \cdots = a_m = 0$
 H_1 : There is at least one $a_m \neq 0; m = 1, 2, \dots, M$

 Calculation of F_{count} or F test statistics can be done using the following formula in Equation (8) as follows [19].

$$F_{count} = \frac{\sum_{i=1}^{n} \frac{(\hat{y}_i - \bar{y})^2}{M}}{\sum_{i=1}^{n} \frac{(\hat{y}_i - \bar{y})^2}{n} - M - 1} \tag{8}$$

 The critical region in testing the base function coefficients simultaneously is obtained by comparing the value of F_{count} with $F_{\alpha(V1,V2)}$, where V_1 can be replaced with M and V_2 can be replaced with $n - M - 1$. M is the number of base functions included in the model and n is the number of samples used. In addition, it can use the $p-$ value which is compared with the significance level (α). If F_{count} is more than $F_{\alpha(M;n-M-1)}$ or the $p-$ value is less than α, the decision to reject H_0 is obtained.

6. Partially test each base function coefficient using the t-test statistic [18]. The hypothesis used in partial testing is as follows.

 H_0 : $a_m = 0; m = 1, 2, \dots, M$

 H_1 : $a_m \neq 0; m = 1, 2, \dots, M$

 The calculation of t_{count} or t-test statistics can be done using the following formula in Equation (9) as follows [19].

$$t_{count} = \frac{\hat{a}_m}{Se(\hat{a}_m)}, \text{with } Se(\hat{a}_m) = \sqrt{var(\hat{a}_m)} \tag{9}$$

 The critical region is obtained by comparing the t_{count} value with $t_{\alpha;n-M}$ or comparing the $p-$ value with the significance level (α). If $|t_{count}| > t_{\frac{\alpha}{2};n-M}$ or the $p-$ value is less than α, the decision to reject H_0 is obtained.

7. Interpret the results and draw conclusions.

3. RESULTS AND DISCUSSION

3.1 Overview of the Democracy Index in Indonesia

In this study, the descriptive statistical values of the variables used are presented in a table of descriptive statistical values, which includes the mean, minimum, and maximum values, then bar charts and scatter plots of the values of each variable. Simple descriptive statistics are used to describe a series of data without drawing general conclusions. Bar charts are used to describe in general the democracy index of each province in Indonesia along with the factors that are suspected, while scatter plots are used to determine the pattern of distribution of research data as well as an initial detection of the use of methods with a nonparametric approach. The description of each research variable is as follows.

Table 2. Descriptive Statistics

Variable	Mean	St. Dev	Min	Province	Max	Province
Y	77.21	5.01	65.55	Papua Barat	85.13	Bali
X_1	73.77	3.76	63.01	Papua Barat	83.55	DKI Jakarta
X_2	70.73	6.85	53.28	NTB	80.56	Sulawesi Utara
X_3	76.45	10.74	33.84	Papua	93.98	DKI Jakarta
X_4	75.69	4.51	64.01	Papua	84.38	Kalimantan Timur
X_5	1.73	1.25	0.55	Bali	6.25	Papua
X_6	65.81	10.69	39.50	Papua	89.69	DI Yogyakarta

Based on Table 2, there are variations in the democracy index and its influencing factors across provinces in Indonesia. The minimum value of some variables is dominated by Papua Province, such as variables X_3, X_4, and X_6. While the maximum values are spread across several other provinces, namely Y in Bali, X_1 and X_3 in DKI Jakarta, X_2 in North Sulawesi, X_4 in East Kalimantan, X_5 in Papua, and X_6 in DI Yogyakarta. The observed disparities indicate that there are large differences in development indicators between regions and more focused policies are needed to improve the quality of development in certain provinces.

Furthermore, the following is a scatter plot that shows the relationship between each predictor variable and the response variable.

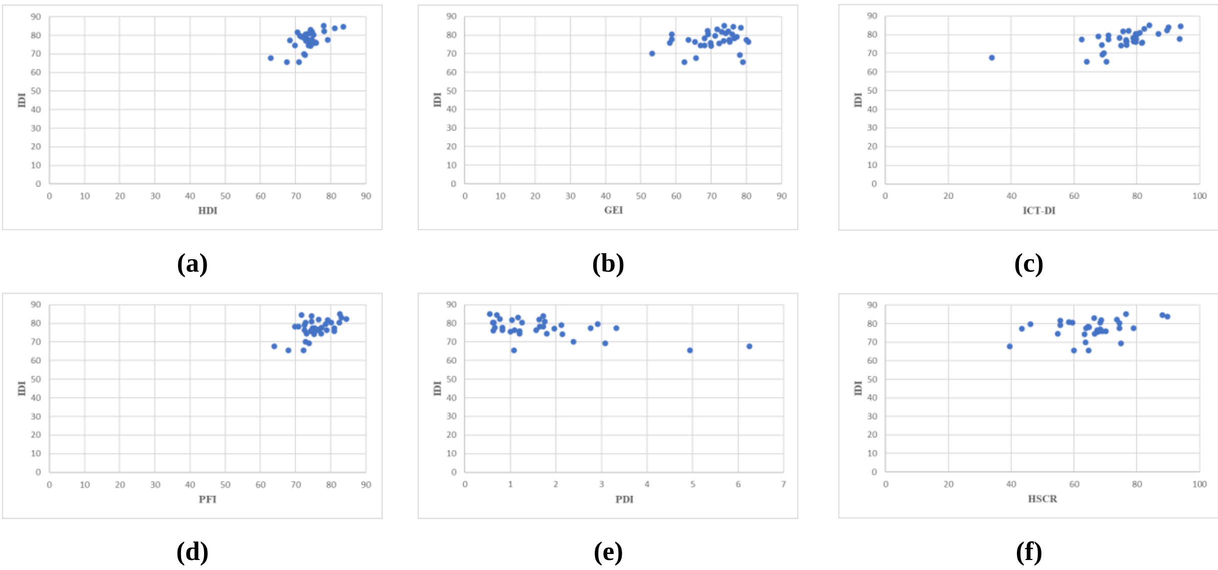

Figure 1. Scatter Plot of Democracy Index in Indonesia with Predictor Variables (a) HDI, (b) GEI, (c) ICT-DI, (d) PFI, (e) PDI, and (f) HSCR

Based on Figure 1, an overview of the distribution of each predictor variables on IDI shows that none exhibit a clear linear or quadratic pattern with the response variable. This indicates that the predictor variables are independent of the IDI calculation itself and are not directly derived from the response variable. Therefore, these variables can be analyzed using a nonparametric regression approach, one of which is MARS modeling.

3.2 Modeling Democracy Index in Indonesia with MARS Model

In this study, the analysis of modeling the democracy index in 34 provinces in Indonesia using the MARS method based on 6 predictor variables is as follows.

3.2.1 Combination of Base Functions

Based on the combination of several BF, MI, and MO, several MARS models of the democracy index in Indonesia were obtained as presented in **Table 3** as follows.

Table 3. **MARS Model Selection Results Using MSE, GCV, and R^2**

Model	BF	MI	MO	MSE	GCV	R^2	Model	BF	MI	MO	MSE	GCV	R^2
1	12	1	0	9.16	17.69	0.68	19	18	2	2	10.71	14.69	0.60
2	12	1	1	6.81	20.02	0.78	20	18	2	3	5.87	14.24	0.80
3	12	1	2	6.98	16.24	0.76	21	18	3	0	7.52	14.70	0.74
4	12	1	3	5.84	14.24	0.80	22	18	3	1	5.77	11.27	0.80
5	12	2	0	7.52	14.70	0.74	23	18	3	2	10.71	14.69	0.60
6	12	2	1	11.54	15.83	0.57	24	18	3	3	5.87	14.24	0.80
7	12	2	2	10.71	14.69	0.60	25	24	1	0	9.75	15.29	0.65
8	12	2	3	5.84	14.24	0.80	26	24	1	1	4.48	16.48	0.86
9	12	3	0	7.52	14.70	0.74	27	24	1	2	6.94	15.73	0.77
10	12	3	1	5.77	11.27	0.80	28	24	1	3	9.07	15.43	0.68
11	12	3	2	10.71	14.69	0.60	29	24	2	0	7.51	14.70	0.74
12	12	3	3	5.87	14.24	0.80	30	24	2	1	4.48	16.48	0.86
13	18	1	0	9.75	15.29	0.65	31	24	2	2	10.71	14.69	0.60
14	18	1	1	4.48	16.48	0.86	32	24	2	3	5.87	14.24	0.80
15	18	1	2	6.94	15.73	0.77	33	24	3	0	7.52	14.70	0.74
16	18	1	3	9.07	15.43	0.68	34	24	3	1	5.77	11.27	0.80
17	18	2	0	7.52	14.70	0.74	35	24	3	2	10.71	14.69	0.60
18	18	2	1	11.54	15.83	0.57	36	24	3	3	5.87	14.24	0.80

Based on **Table 3**, models 10, 22, dan 34 are identified as the best model, each with a GCV value of 11.27, an MSE of 5.77, and an R^2 of 0.80. The R^2 value of 0.80 indicates that 80% of the variability in the democracy index response variable (Y) can be explained by the predictor variables (X). Among these, model 10 with BF = 12, MI = 3, and MO = 1, was selected as the final model based on the principle of parsimony, which prioritizes simpler models with fewer parameters while maintaining high predictive accuracy.

3.2.2 Base Functions Estimation

The best estimated base function for modeling democracy index in Indonesia is presented in **Table 4** as follows.

Table 4. **Best Model Base Function Estimation**

Base Function (BF)	Parameter Estimation
$BF_1 = max(0;\ X_3 - 33.84)$	0.272
$BF_2 = max(0;\ X_6 - 59.99)$	-
$BF_5 = max(0;\ 74.90 - X_2) * BF1$	-0.006
$BF_7 = max(0; 70.91 - X_3) * BF2$	-0.308
$BF_9 = max(0;\ 70.47 - X_1) * BF5$	-0.007

Based on **Table 4**, the MARS model for estimating the democracy index in Indonesia is obtained as follows.

$$\hat{Y} = 67.70 + 0.272\, BF_1 - 0.006\, BF_5 - 0.308\, BF_7 - 0.007\, BF_9 \tag{10}$$

After obtaining the MARS equation to estimate the democracy index in Indonesia, the following is the interpretation of each base function that plays a significant role in **Equation (10)**.

1. Base One Function (BF_1)

$$BF_1 = \begin{cases} (X_3 - 33.84);\ for\ X_3 > 33.84 \\ 0 \qquad ;\ for\ others \end{cases}$$

The interpretation of the base function value of one (BF_1) with a coefficient of 0.272 means that each one unit increase in BF_1 in provinces with X_3 values greater than 33.84 will increase the IDI by 0.272, with base functions BF_2, BF_5, BF_7, and BF_9 held constant.

2. Base Five Function (BF_5)

$$BF_5 = \begin{cases} (74.90 - X_2)(X_3 - 33.84)\ ; \ for\ X_2\ < 74.90, X_3\ > 33.84 \\ 0 \qquad\qquad ;\ for\ others \end{cases}$$

The interpretation of the base function value of one (BF_5) with a coefficient of -0.006 means that each one unit increase in BF_5 in provinces with X_2 values lower than 74.90 and X_3 greater than 33.84 will decrease the IDI by 0.006, with base functions BF_1, BF_2, BF_7, and BF_9 held constant.

3. Base Seven Function (BF_7)

$$BF_7 = \begin{cases} (70.91 - X_3)(X_6 - 59.99)\ ; \ for\ X_3\ < 70.91, X_6\ > 59.99 \\ 0 \qquad\qquad ;for\ others \end{cases}$$

The interpretation of the base function value of one (BF_7) with a coefficient of -0.308 means that each one unit increase in BF_5 in provinces with X_3 values lower than 70.91 and X_6 greater than 59.99 will decrease the IDI by 0.272, with base functions BF_1, BF_2, BF_7, and BF_9 held constant.

4. Base Nine Function (BF_9)

$$BF_9 = \begin{cases} (70.47 - X_1)(74.90 - X_2)(X_3 - 33.84);\ X_1\ < 70.47, X_2\ < 70.90, X_3\ > 33.84 \\ 0 \qquad\qquad ;\ for\ others \end{cases}$$

The interpretation of the base function value of one (BF_9) with a coefficient of 0.007 means that each one unit increase in BF_9 in provinces with X_1 values lower than 70.47, X_2 lower than 70.90 and X_3 values greater than 33.84 will decrease the IDI by 0.007, with base functions BF_1, BF_2, BF_5, and BF_7 held constant.

3.2.3 Residual Normality Assumption Test

In testing the assumption of residual normality, the following hypothesis formulation is used.

H_0 : Residuals are normally distributed
H_1 : Residuals are not normally distributed

In conducting the residual assumption test, testing is carried out using software assistance. The results of the calculation of test statistics using the Kolmogorov-Smirnov test are as follows.

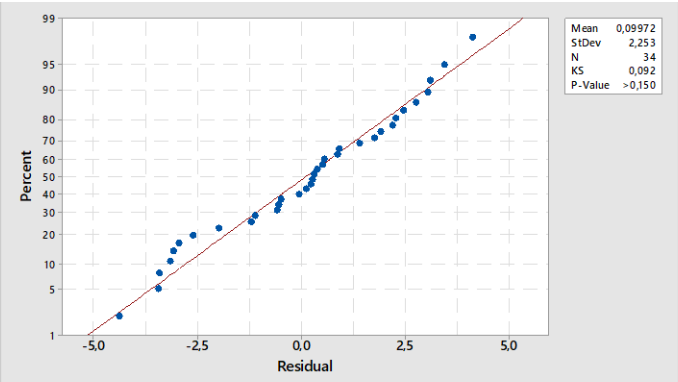

Figure 2. Plot of Residual Normality Assumption Test

The critical region in this test is determined by rejecting H_0 if the $p-$ value is smaller than the significance level (α). Based on **Figure 2**, it can be seen that the $p-$value is > 0.150, which is greater than the significance level (α = 0.05). Therefore, the decision fails to reject H_0 with the conclusion that the residuals are normally distributed.

3.3 MARS Model Significance Test

This test is conducted to determine whether there is a significant relationship between the predictor variable and the response variable.

3.3.1 Simultaneous Test of MARS Model Base Function Coefficients

This test is conducted using the F test statistic to determine whether all base function coefficients in the MARS model simultaneously affect the response variable. The hypothesis used in this test is as follows.

$H_0 : a_1 = a_5 = a_7 = a_9$
H_1 : There is at least one $a_m \neq 0$; $m = 1, 5, 7, 9$

Based on the results of the F test statistical calculation, the F_{count} value is 28.72, which more than $F_{(0.05;5;28)} = 2.59$. In addition, a $p -$ value of 0.1032×10^{-8} is also obtained which is also less than the significance level = 0.05, so the decision to reject H_0 is obtained and it can be concluded that there is a relationship between the base function coefficients and the response variable.

3.3.2 Partial Test of MARS Model Base Function Coefficients

This test is conducted to determine whether each base function coefficient in the MARS model partially affects the response variable. The hypothesis used in this test is as follows.

$H_0 : a_m = 0 ; m = 1, 5, 7, 9$
$H_1 : a_m \neq 0 ; m = 1, 5, 7, 9$

The test statistical results of the partial testing of the MARS model base function coefficients are presented in Table 5 as follows.

Table 5. Partial Test Results of MARS Model Base Function Coefficients

Parameter	Estimate	S.E.	T. Ratio	$p -$ value
$Constan$	67.70	1.83	37.07	0.9992×10^{-15}
BF_1	0.272	0.042	6.50	0.4137×10^{-6}
BF_5	-0.006	0.002	-3.49	0.002
BF_7	-0.308	0.060	-5.13	0.1762×10^{-4}
BF_9	-0.007	0.002	-3.81	0.6691×10^{-3}

Based on Table 5, the $|t_{count}|$ value of each base function in the model is more $t_{(0.025;\ 29)} = 2.05$. In addition, the $p -$ value of each base function in the model is less than the significance level (α = 0.05). Therefore, we can reject H_0 and conclude that there is a relationship between the base function coefficients and the response variable.

3.4 Variable Importance Level

The variable importance level is used to rank the predictor variables that affect the response variable. The level of variable importance in modeling the democracy index data in Indonesia is presented in Table 6 as follows.

Table 6. Variable Importance Level

Variable	Variable Name		Level of Importance	GCV Reduction
X_3	Information and Communication Technology Development Index	ICT-DI	100%	25.90
X_6	High School Completion Rate	HSCR	63.81%	17.23
X_2	Gender Empowerment Index	GEI	55.81%	15.83
X_1	Human Development Index	HDI	39.44%	13.55
X_4	Press Freedom Index	PFI	0%	11.27
X_5	Poverty Depth Index	PDI	0%	11.27

Based on Table 6, there is an importance level that shows how much influence the predictor variable has on the response variable, while the GCV reduction shows how much each variable contributes to improving model quality by reducing prediction error or variability. Therefore, the predictor variable with the greatest influence on the response variable is the ICT-DI variable (X_3) with an importance level of 100%, which can also reduce the GCV value by 25.90 when the variable is included in the model.

Furthermore, the predictor variables that influence the response variable are the high school education completion rate variable (X_6) with an importance level of 63.81%, GEI (X_2) with an importance level of 55.81%, then followed by the HDI variable (X_1) with an importance level of 39.44%. Meanwhile, the predictor variables that have an importance level of 0% are the PFI (X_4) and PDI (X_5) variables.

4. CONCLUSION

Based on the results of the analysis in this study, the best MARS model was obtained with a combination of BF = 12, MI = 3, and MO = 1 which had the smallest GCV value of 11.27 and an R^2 value of 80%. Among the candidate models, this model was selected based on the principle of parsimony, favoring a simpler structure with fewer parameters while maintaining high predictive accuracy. Furthermore, it was concluded that all predictor variables used in the model significantly influenced the democracy index in Indonesia. The ICT-DI variable has a dominant contribution (100%) to the democracy index, followed by the variable of HSCR (63.81%), GEI (55.81%), and the HDI variable contributes 39.44%.

Variables with high contributions in the IDI certainly need to be given more attention to improve Indonesia's democracy. The government needs to improve the access to and quality of digital infrastructure, especially in remote and underdeveloped areas, to ensure broad and equitable access to information. These improvements will enable people to engage more fully in the political process, better understand relevant issues, and actively participate in elections and public discussions. The government also needs to increase access to secondary education in all provinces and reduce regional disparities to improve the quality of education in Indonesia. Gender empowerment can also be improved by increasing women's participation in decision-making, eliminating gender-based discrimination, and opening wider access for women in the economic and political fields. In addition, improving the quality of health services and people's living standards are also important in supporting the improvement of the democracy index in Indonesia.

For future research, it is recommended to explore alternative regression-based methods to address some limitations of MARS. Although MARS provides flexible spline-based modeling, it can be sensitive to overfitting, especially with small sample sizes or highly correlated predictors. Future studies could consider approaches such as penalized regression methods to improve variable selection and reduce model complexity. Additionally, Generalized Additive Models (GAM) or semi-parametric regression techniques could offer a balance between flexibility and interpretability. Incorporating regularization and cross-validation techniques will help enhance model generalizability. Finally, applying these models to longitudinal or panel data could better capture temporal dynamics influencing the democracy index.

AUTHOR CONTRIBUTIONS

Toha Saifudin: Conceptualization, Funding acquisition, Methodology, Project administration. Suliyanto: Data Curation, Project Administration, Visualization, Writing-Original Draft. Galuh Cahya Nugraha: Methodology, Supervision. Hanny Valida: Formal analysis, Resources, Software, Writing - original draft, Writing - review & editing. Muhammad Hafizuddin Nahar: Resources, Software, Writing - original draft. Regina Fortuna: Data curation, Validation, Writing - original draft. All authors discussed the results and contributed to the final manuscript.

FUNDING STATEMENT

This research was conducted without the support of any specific grant from funding agencies in the public, commercial, or not-for-profit sectors

ACKNOWLEDGMENT

The authors sincerely thank God Almighty for blessings, guidance, and unwavering support throughout the course of this research. Appreciation is also extended to Universitas Airlangga, particularly the Statistics Study Program, Faculty of Science and Technology, for their continuous support, academic resources, and institutional facilitation that have been essential to this study. In addition, we express our sincere appreciation to Statistics Indonesia – BPS, for granting access to publicly available data that served as the foundation of this study. Lastly, the authors acknowledge the moral support and understanding of their families and peers. Constructive feedback and suggestions for further improvement of this research are sincerely welcomed and appreciated

CONFLICT OF INTEREST

The authors declare no conflicts of interest to report study.

REFERENCES

[1] D. T. H. Hutabarat, N. Sinta, N. A. Dwiva, M. A. Raihandi, A. Ardiansyah, S. Febrian and G. Akbar, "MEMAHAMI DALAM PENDIDIKAN DEMOKRASI," *Review of Multidisiplinary Education, Culture and Pedagogy,* vol. 1, no. 1, pp. 103-109, 2021. doi: https://doi.org/10.55047/romeo.v1i1.60

[2] Ibrahim, "MENAKAR KEDALAMAN PENGUKURAN DEMOKRASI MODEL INDEKS DEMOKRASI INDONESIA (IDI): BEBERAPA CATATAN SUBSTANTIF DARI KEPULAUAN BANGKA BELITUNG," *Masyarakat, Kebudayaan dan Politik,* vol. 30, no. 2, pp. 133-149, 2017. doi: https://doi.org/10.20473/mkp.V30I22017.133-149

[3] R. A. Putra, "INDEKS DEMOKRASI INDONESIA CATAT SKOR TERENDAH DALAM SEJARAH," DW.com, 4 Feb 2021. [Online]. Available: https://www.dw.com/id/indeks-demokrasi-indonesia-catat-skor-terendah-dalam-sejarah/a-56448378. [Accessed 30 Sept 2024].

[4] T. Subarkah, "Angka Indeks Terus Turun, Demokrasi Indonesia Masih Cacat," Media Indonesia, 11 Sept 2023. [Online]. Available: https://mediaindonesia.com/politik-dan-hukum/651955/angka-indeks-terus-turun-demokrasi-indonesia-masih-cacat#google_vignette. [Accessed 29 Sept 2024].

[5] S. Syafrudin, "DeMOKRASI KONSTITUSIONAL DI INDONESIA: DINAMIKA DAN TANTANGAN," *Jurnal Konstitusi,* vol. 12, no. 1, pp. 23-47, 2015.

[6] F. Darnawaty and N. Purnasari, "ANALISIS PENGARUH PERTUMBUHAN EKONOMI, PERTUMBUHAN PENDUDUK, DAN ASPEK PENDIDIKAN TERHADAP IPM DI SUMATERA UTARA," *EKOMBIS Sains: Jurnal Ekonomi, Keuangan dan Bisnis,* vol. 4, no. 2, pp. 17-25, 2019. doi: https://doi.org/10.24967/ekombis.v4i2.467

[7] A. Z. Abidin, E. Siswati and A. Wahyudi, DATA INDEKS DEMOKRASI INDONESIA (IDI) DI KOTA BLITAR TAHUN 2018, Surabaya: Indomedia Pustaka, 2020.

[8] Suprapto, "ESTIMASI INTERVAL KURVA REGRESI NONPARAMETRIK SPLINE TRUNCATED MULTIVARIABLE," Surabaya, 2018.

[9] A. Putri and S. Rahayu, "PENGARUH KEMERDEKAAN PERS TERHADAP PARTISIPASI POLITIK MASYARAKAT DI INDONESIA," *Jurnal Demokrasi dan Media,* vol. 15, no. 2, pp. 45-60, 2021.

[10] Y. Sufriadi, "PENERAPAN HUKUM PROGRESIF DALAM PENEGAKAN HUKUM DI TENGAH KRISIS DEMOKRASI," *Jurnal Hukum IUS QUIA IUSTUM,* vol. 17, no. 2, pp. 233-248, 2010. doi: https://doi.org/10.20885/iustum.vol17.iss2.art3

[11] I. Yusuf and A. Hamid, "PENDIDIKAN MENENGAH DAN PARTISIPASI POLITIK DI INDONESIA: STUDI EMPIRIS," *Jurnal Analisis Kebijakan Pendidikan,* vol. 10, no. 1, pp. 23-40, 2022. doi: https://doi.org/10.21831/sakp.v10i3.17457

[12] H. Ramdhani, "PENGARUH INFLASI, NILAI TUKAR, DAN SUKU BUNGA TERHADAP INDEKS DEMOKRASI INDONESIA PADA TAHUN 2009-2020," *Entita: Jurnal Pendidikan Ilmu Pengetahuan Sosial dan Ilmu-Ilmu Sosial,* vol. 6, no. 1, pp. 33-46, 2024. doi: https://doi.org/10.19105/ejpis.v6i1.12540

[13] D. A. Dani, A. Dewi and L. Ni'matuzzahroh, "STUDI SIMULASI DAN APLIKASI: ESTIMASI DERET FOURIER PADA PEMODELAN REGRESI NONPARAMETRIK," in *Prosiding Seminar Nasional Matematika dan Statistika*, 2022.

[14] D. A. Syahbani, S. Anwar and N. Salwa, "KESEJAHTERAAN RUMAH TANGGA DI KABUPATEN PIDIE: IDENTIFIKASI FAKTOR DAN PENGARUH KATEGORI WILAYAH," *Jurnal Ekonomi dan Pembangunan,* vol. 31, no. 1, pp. 59-82, 2023.

[15] G. F. Panggabean and A. Mansyur, "PENERAPAN MULTIVARIATE ADAPTIVE REGRESSION SPLINES PADA LAJU PRODUK DOMESTIK REGIONAL BRUTO MENURUT LAPANGAN USAHA DI PROVINSI SUMATERA UTARA," *SAINTEK,* vol. 2, no. 1, pp. 159-171, 2023. doi: https://doi.org/10.58169/saintek.v2i1.160

[16] Irwan and M. Wardani, "MEMODELKAN FAKTOR-FAKTOR YANG MEMPENGARUHI GIZI BURUK BALITA DENGAN METODE MULTIVARIATE ADAPTIVE REGRESSION SPLINE (MARS)," *Jurnal MSA,* vol. 5, no. 1, pp. 69-74, 2017. doi: https://doi.org/10.24252/jmsa.V5N1P69

[17] M. R. Mattalunru, S. Annas and M. K. Aidid, "APLIKASI MULTIVARIATE ADAPTIVE REGRESSION SPLINE (MARS) UNTUK MENGETAHUI FAKTOR YANG MEMPENGARUHI CURAH HUJAN DI KOTA MAKASSAR," *VARIANSI: Journal of Statistics and Its Application on Teaching and Research,* vol. 4, no. 1, pp. 9-19, 2022.

[18] S. Risambessy, S. N. Aulele and F. K. Lembang, "ANALISIS MISKLASIFIKASI DATA AKREDITASI SEKOLAH DASAR DI KOTA AMBON MENGGUNAKAN METODE MULTIVARIATE ADAPTIVE REGRESSION SPLINE," *Jurnal Matematika, Statistika & Komputasi,* vol. 18, no. 3, pp. 394-406, 2022. doi: https://doi.org/10.20956/j.v18i3.19451

[19] W. Wicaksono, "PEMODELAN MULTIVARIATE ADAPTIVE REGRESSION SPLINE (MARS) PADA FAKTOR-FAKTOR RESIKO ANGKA KESAKITAN DIARE (STUDI KASUS: ANGKA KESAKITAN DIARE DI JAWA TENGAH, JAWA TIMUR, DAN DAERAH ISTIMEWA YOGYAKARTA TAHUN 2011)," *Jurnal Gaussian,* vol. 3, no. 2, pp. 253-262, 2014.