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Forecasting the Human Development Index of Toba Regency Using Holt's Double Exponential Smoothing

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Abstract: The Human Development Index (HDI) of Toba Regency has generally shown a long-term upward trend, although a substantial change occurred during the observation period. Reliable forecasting is required to support regional planning, resource allocation, and policy evaluation; however, studies applying Holt's two-parameter *Double Exponential Smoothing* to long-term HDI data at the regency level remain limited. **Objective:** This study aimed to model the historical pattern, evaluate forecasting accuracy, and project the HDI of Toba Regency for 2026–2030 using Holt's *Double Exponential Smoothing*. **Method:** This quantitative time-series forecasting study used 22 annual secondary observations of Toba Regency's HDI covering 2004–2025, obtained from Badan Pusat Statistik. All annual observations within the study period were included. The level and trend smoothing parameters were determined through a *trial-and-error* procedure based on the smallest forecasting error. Model performance was evaluated using *Mean Absolute Deviation* (MAD), *Root Mean Squared Error* (RMSE), and *Mean Absolute Percentage Error* (MAPE). **Findings:** The optimal parameters were $\alpha = 0.96$for level smoothing and $\beta = 0.05$for trend smoothing. The model produced a MAD of 0.57, an RMSE of 1.34, and a MAPE of 0.77%, indicating a low *in-sample* forecasting error. The HDI was projected to increase from 79.60 in 2026 to 80.04 in 2027, 80.49 in 2028, 80.93 in 2029, and 81.37 in 2030. The forecast indicates a transition from the high to the very high HDI category beginning in 2027. **Implications:** These projections can support the Toba Regency Government in establishing development priorities and evaluating policies related to health, education, and living standards, while remaining subject to external socioeconomic and policy changes. **Originality:** This study provides a specific regency-level application of Holt's separate level-and-trend smoothing parameters to a 22-year HDI series and identifies the projected timing of Toba Regency's transition into the very high HDI category.
Keywords: Double exponential smoothing; forecasting; Holt's method; human development index; Toba Regency.

INTRODUCTION

Human development constitutes a fundamental objective of regional development because development outcomes should be assessed not only through economic growth but also through improvements in people's capabilities and quality of life. The Human Development Index (HDI) is a composite indicator covering three basic dimensions: a long and healthy life, access to knowledge, and a decent standard of living (United Nations Development Programme [UNDP], 2024). In Indonesia, these dimensions are represented by life expectancy at birth, expected years of schooling, mean years of schooling, and adjusted per capita expenditure (Badan Pusat Statistik [BPS], 2024). HDI values are classified into four categories: low for values below 60, medium for values from 60 to below 70, high for values from 70 to below 80, and very high for values of 80 or above (BPS, 2024). Therefore, monitoring and forecasting HDI can provide evidence to support the evaluation and formulation of regional policies concerning health, education, income, and living standards.

Toba Regency is one of the regions in North Sumatra Province that has demonstrated long-term improvement in human development. The historical data used in this study show that its HDI generally increased during 2004–2025, despite a substantial decline recorded around 2014. In the most recent period, the index increased from 75.16 in 2020 to 79.17 in 2025, placing the regency near the threshold of the very high HDI category. This development creates a need to estimate whether the recent upward movement is likely to continue and when the index may exceed the threshold of 80. Reliable forecasts can help the local government establish realistic development targets, anticipate changes in public-service demand, allocate regional resources, and evaluate whether interventions in health, education, and economic welfare remain aligned with the expected direction of human development. Nevertheless, forecasts should be interpreted as evidence-based estimates rather than certain future outcomes because unexpected policy, demographic, and socioeconomic changes may alter the observed trend.

Time-series forecasting provides a systematic framework for estimating future observations from historical patterns. The selection of a forecasting model must correspond to the characteristics of the data, including its level, trend, seasonality, variation, and possible structural changes (Box, Jenkins, Reinsel, & Ljung, 2015; Chatfield, 2000). ARIMA is widely applied to time-series data, but its implementation requires model identification, stationarity assessment, and diagnostic checking (Box et al., 2015). Lestari and Handayani (2021) applied ARIMA to forecast HDI in Indonesia, demonstrating the usefulness of time-series analysis for estimating future human development outcomes. However, for a relatively short annual series with a persistent non-seasonal trend, exponential smoothing provides a simpler and more adaptive alternative. Forecasting methods should consequently be selected based on empirical performance rather than computational complexity alone (Makridakis, Wheelwright, & Hyndman, 1998; Montgomery, Jennings, & Kulahci, 2015).

Exponential smoothing generates forecasts by assigning greater weights to recent observations and progressively smaller weights to older observations. This method has developed from basic level smoothing into a family of models capable of accommodating trend and seasonal components (Gardner, 1985, 2006). Holt's method extends simple exponential smoothing by updating the level and trend separately through two smoothing parameters, making it appropriate for non-seasonal data exhibiting a systematic trend (Holt, 2004; Hyndman & Athanasopoulos, 2021). The method can also be expressed within a state-space framework, enabling systematic parameter estimation, model selection, and the construction of prediction intervals (Hyndman, Koehler, Snyder, & Grose, 2002; Hyndman, Koehler, Ord, & Snyder, 2008). Forecast accuracy must subsequently be evaluated using appropriate error measures because different indicators capture different aspects of forecasting performance. MAD describes the average absolute error, RMSE gives greater weight to large deviations, and MAPE expresses the average error relative to actual observations, although percentage-based measures must be interpreted carefully (Hyndman & Koehler, 2006).

Previous studies have demonstrated the applicability of exponential smoothing to socioeconomic and human development data. Ramadhan, Situmorang, and Tarigan (2023) reported that the effectiveness of a smoothing method depends on the pattern of the welfare indicator being forecast. Listiowarni, Dewi, and Hapantenda (2020) similarly found that the selection of the forecasting method and its smoothing parameters affects prediction errors. In the specific context of HDI, Syahputra and Utari (2023) employed *Double Exponential Smoothing* to forecast the HDI of Karawang Regency and showed that the method could capture its growth trend. Balamakin and Osan (2025) also applied Brown's *Double Exponential Smoothing* to the HDI of East Nusa Tenggara Province and obtained an increasing projection for subsequent periods. However, previous studies have generally focused on different regions, used alternative DES formulations, or provided limited discussion of the implications of the level and trend parameters. Empirical evidence regarding the application of Holt's two-parameter DES to the annual HDI series of Toba Regency therefore remains limited.

Based on this research gap, this study aims to model and forecast the Human Development Index of Toba Regency using Holt's *Double Exponential Smoothing*. Annual HDI data for 2004–2025 are used to determine the combination of the level parameter (α) and trend parameter (β) that generates the lowest forecasting error. Model performance is evaluated using MAD, RMSE, and MAPE before the selected model is applied to forecast HDI for 2026–2030. This study contributes empirical evidence regarding the suitability of Holt's method for forecasting a regional human development indicator with a long-term trend. The resulting forecasts are expected to support the Government of Toba Regency in evaluating development progress and formulating policies related to healthcare accessibility, educational attainment, employment, and community living standards.

RESEARCH METHOD

This study employed a quantitative time-series forecasting approach to model and project the Human Development Index (HDI) of Toba Regency. The analysis used annual secondary HDI data covering the period 2004–2025. The data were obtained from Badan Pusat Statistik (BPS) of Toba Regency, the official institution responsible for publishing regional statistical information. Historical time-series data were used to identify the underlying movement of HDI and estimate its values for the subsequent five-year period, namely 2026–2030. A preliminary examination indicated a general long-term upward pattern; therefore, a forecasting method capable of accommodating a trend component was considered appropriate.

The forecasting method applied in this study was Holt's Double Exponential Smoothing (DES). Unlike Single Exponential Smoothing, which primarily estimates the level of a series, Holt's method incorporates both level and trend components and is therefore suitable for time-series data exhibiting systematic changes over time (Montgomery, Jennings, & Kulahci, 2015). Previous applications have also demonstrated the relevance of Double Exponential Smoothing for forecasting HDI and other data characterized by trend patterns (Listiowarni, Dewi, & Hapantenda, 2020; Syahputra & Utari, 2023). The level component at period t was calculated using Equation (1).

$$L_t = \alpha Y_t + (1 - \alpha)(L_{t-1} + T_{t-1}) \quad (1)$$

In Equation (1), L_t represents the estimated level at period t, Y_t denotes the actual HDI value at period t, α is the level smoothing parameter with $0 < \alpha < 1$, and T_{t-1} represents the estimated trend from the preceding period. The trend component was estimated using Equation (2).

$$T_t = \beta(L_t - L_{t-1}) + (1 - \beta)T_{t-1} \quad (2)$$

In Equation (2), T_t represents the estimated trend at period t, while β denotes the trend smoothing parameter with $0 < \beta < 1$. The forecast for h periods ahead was generated using Equation (3), where $\hat{Y}_{t+h}$ denotes the forecast value for h periods after period t. Through these equations, the model continuously updates the estimated level and trend before producing future forecasts. Holt's approach is particularly useful when a series contains a persistent trend without a seasonal component (Montgomery et al., 2015).

$$\hat{Y}_{t+h} = L_t + hT_t \quad (3)$$

The smoothing parameters α and β were determined through a trial-and-error procedure to identify the combination that produced the smallest forecasting error. Different combinations of the level and trend smoothing parameters were evaluated, and the combination with the best error performance was selected as the final model. Parameter selection is important because the values of α and β determine the responsiveness of the model to recent observations and changes in the underlying trend. A relatively large α gives greater weight to recent observations, whereas β determines the rate at which the estimated trend responds to changes in the series. The selected parameters were subsequently applied to forecast the HDI of Toba Regency for 2026–2030.

Forecasting performance was evaluated using Mean Absolute Deviation (MAD), Root Mean Squared Error (RMSE), and Mean Absolute Percentage Error (MAPE). The forecasting error for each observation was calculated from the difference between the actual and corresponding forecast values. MAD measures the average absolute magnitude of forecasting errors without considering their direction and was calculated using Equation (4). RMSE assigns a greater penalty to relatively large errors because individual errors are squared before averaging and was calculated using Equation (5). Smaller MAD and RMSE values indicate that the forecast values are closer to the observed values.

$$MAD = (1/n) \Sigma^{n}_{t=1} |Y_t - \hat{Y}_t| \quad (4)$$

$$RMSE = \sqrt{[(1/n) \Sigma^{n}_{t=1} (Y_t - \hat{Y}_t)^2]} \quad (5)$$

MAPE was used as the percentage-based measure of forecasting accuracy because it expresses the average absolute error relative to the actual observations. MAPE was calculated using Equation (6), where Y_t is the actual HDI value, $\hat{Y}_t$ is the forecast value, and n is the number of observations evaluated. A smaller MAPE indicates higher forecasting accuracy. Based on the classification used in the study, a MAPE below 10% is categorized as very good, 10–20% as good, 20–50% as adequate, and above 50% as poor. The use of percentage-based error measures is consistent with forecasting studies that compare actual and predicted values (Listiowarni et al., 2020). MAD, RMSE, and MAPE were jointly considered before the selected Holt model was used to generate HDI projections for 2026–2030.

$$MAPE = (100\%/n) \Sigma^{n}_{t=1} |(Y_t - \hat{Y}_t)/Y_t| \quad (6)$$

The analysis was conducted sequentially by compiling annual HDI data for 2004–2025, examining the historical pattern, applying Holt's Double Exponential Smoothing, determining the optimal smoothing parameters, calculating forecasting errors, and generating five-year-ahead projections. The resulting forecasts were interpreted in relation to the historical development of HDI in Toba Regency and compared with relevant previous studies. Because the model relies exclusively on historical HDI values, the projections represent statistical estimates based on the continuation of the observed level and trend rather than deterministic predictions. External factors, including changes in economic conditions, government policies, health and education programs, demographic dynamics, and other structural changes, were not explicitly incorporated into the model. This limitation was considered when interpreting the projected

RESULT AND DISCUSSION

Historical Development of the Human Development Index

The Human Development Index data of Toba Regency for 2004–2025 generally exhibit a long-term upward trend, although a substantial decline occurred during the middle of the observation period. From 2004 to 2013, the HDI increased consistently from 73.80 to 77.49. This pattern indicates gradual improvement in the dimensions of health, education, and decent living standards. However, the recorded HDI declined sharply to 72.49 in 2014. Following this decline, the index recovered and subsequently showed a relatively stable increasing trend from 2015 until it reached its highest observed value of 79.17 in 2025.

The substantial change around 2014 should be interpreted carefully because it may represent an empirical change, a revision in the source data, or a change in the HDI calculation methodology. This observation should therefore be verified against the official publication of Badan Pusat Statistik before the manuscript is finalized. The sharp decline may also affect the estimated level and trend components of the forecasting model. Nevertheless, the overall movement of the series indicates a positive long-term trend, supporting the use of Holt's Double Exponential Smoothing, which is designed for non-seasonal time-series data containing a trend component (Montgomery, Jennings, & Kulahci, 2015).

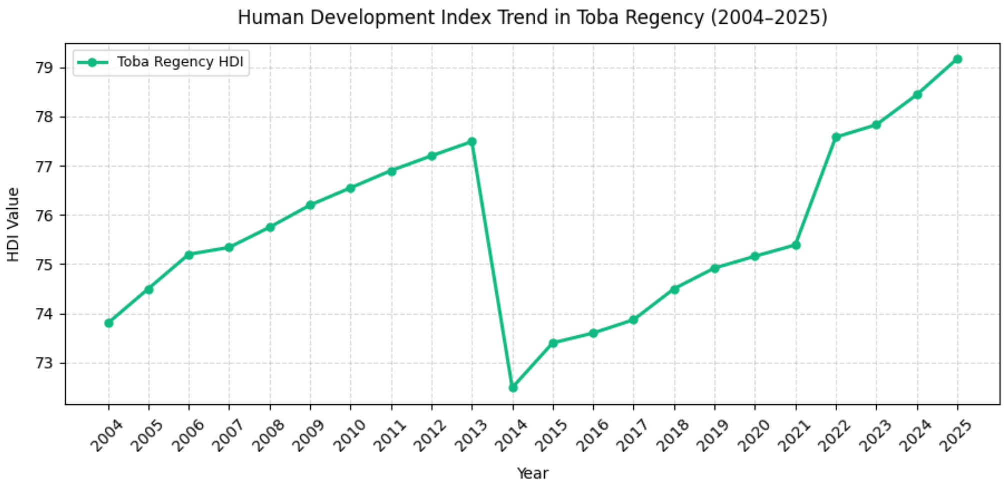

Figure 2. Development of the Human Development Index of Toba Regency, 2004–2025

The descriptive statistics of the HDI data are presented in Table 2. The observed values ranged from 72.49 to 79.17, resulting in a range of 6.69 points. The mean HDI was 75.69, while the median was 75.36. The relatively small difference between the mean and median indicates that the distribution of the observations was reasonably balanced around its central value. The variance of 3.18 also demonstrates that most observations were concentrated relatively close to the mean.

Table 2. Descriptive Statistics of the Human Development Index of Toba Regency

Maximum	Minimum	Range	Mean	Median	Variance
79.17	72.49	6.69	75.69	75.36	3.18

The relatively limited range and variance indicate that the annual HDI values did not fluctuate extensively throughout the observation period, except for the decline recorded around 2014. However, low variance should not be interpreted as evidence that the data are entirely homogeneous because the observations are arranged chronologically and contain a systematic trend. Consequently, the temporal structure of the series remains more important for forecasting than its descriptive dispersion alone.

Holt's Double Exponential Smoothing Model

The Holt model was estimated using two smoothing parameters: the level parameter α and the trend parameter β. Different parameter combinations were evaluated through a trial-and-error procedure, and the combination producing the smallest forecasting error was selected. The optimal parameters obtained from this process are presented in Table 3.

Table 3. Optimal Smoothing Parameters

Parameter	Component	Value
α	Level smoothing	0.96
β	Trend smoothing	0.05

The value of α = 0.96 indicates that the estimated level gives a very high weight to the most recent actual observation. The model therefore responds rapidly to changes in the current HDI value. This characteristic is relevant to the observed series because the data contain a substantial change around 2014. However, a high level parameter may also make the fitted values sensitive to unusual observations or possible structural changes in the data.

Conversely, the relatively small value of β = 0.05 indicates that the trend component is updated gradually. Short-term changes have a limited influence on the estimated long-term direction of the series. The combination of a high α and low β therefore produces a model that responds quickly to changes in the current level while maintaining a relatively stable trend estimate. This parameter structure is consistent with the recent HDI pattern of Toba Regency, which shows gradual and relatively stable growth after the earlier decline.

The selection of appropriate smoothing parameters is important because different combinations may produce different levels of forecasting accuracy. Listiowarni, Dewi, and Hapantenda (2020) similarly demonstrated that parameter selection significantly affects the performance of Double Exponential Smoothing. The present result also supports the application of DES to HDI data with an observable trend, as reported by Syahputra and Utari (2023) in forecasting the HDI of Karawang Regency.

Forecasting Accuracy

The forecasting performance of the selected Holt model was evaluated using MAD, RMSE, and MAPE. The results are presented in Table 4.

Table 4. Forecasting Error Measures

Error measure	Value
MAD	0.57
RMSE	1.34
MAPE	0.77%

The MAD value of 0.57 indicates that the fitted HDI values differed from the actual observations by approximately 0.57 points on average. The RMSE value of 1.34 is higher than the MAD because RMSE assigns a greater penalty to relatively large errors. This difference suggests that one or more observation periods generated larger deviations, which may be associated with the substantial change in the HDI series around 2014.

The MAPE value of 0.77% falls below the 10% threshold and is therefore categorized as very good based on the classification applied in this study. These results indicate that the selected Holt model can reproduce the historical HDI pattern with a relatively low average percentage error. The finding is consistent with previous research demonstrating that exponential smoothing can produce low forecasting errors when applied to data with an identifiable trend (Listiowarni et al., 2020; Syahputra & Utari, 2023).

Nevertheless, these error values should be interpreted as measures of in-sample fitting if they were calculated using the same observations employed to estimate the model. A low in-sample error indicates that the model fits the historical data well but does not independently confirm its performance on previously unseen observations. Therefore, the claim of forecasting accuracy should remain limited to the evaluated historical sample unless an out-of-sample validation or training–testing procedure is conducted.

HDI Forecasts for 2026–2030

After the optimal parameters and forecasting errors had been determined, the selected model was used to project the HDI of Toba Regency for 2026–2030. The forecasting results are presented in Table 5.

Table 5. Forecasted Human Development Index of Toba Regency, 2026–2030

Year	Forecasted HDI	HDI category
2026	79.60	High
2027	80.04	Very high
2028	80.49	Very high
2029	80.93	Very high
2030	81.37	Very high

The forecast shows a consistent increase from 79.60 in 2026 to 81.37 in 2030. The total projected increase is 1.77 points over five years, equivalent to an average increase of approximately 0.44 points per year. The nearly constant annual increment reflects the linear trend structure generated by Holt's method.

An important finding is the projected transition in the HDI classification. The forecast for 2026 remains within the high category because its value is below 80. In 2027, the projected value reaches 80.04 and therefore enters the very high category based on the classification used by BPS (2024). The model subsequently projects that this category will be maintained through 2030. However, this transition represents a statistical projection rather than confirmation that the very high category will necessarily be achieved.

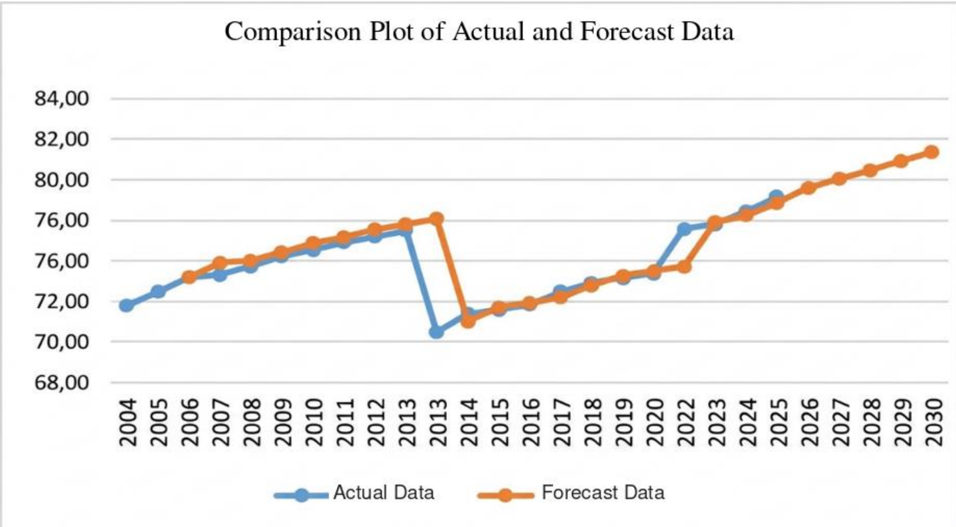

Figure 3. Comparison of Actual and Forecasted HDI Values of Toba Regency

The comparison between the actual and fitted values indicates that the Holt model generally follows the historical movement of the HDI series. Small differences between the actual and estimated values remain visible in several periods, particularly around the substantial decline in the middle of the series. This condition is reasonable because Holt's DES is primarily designed to represent level and trend and does not explicitly model structural breaks or sudden interventions. The continued increase projected for 2026–2030 is consistent with the recent historical trend but assumes that the underlying development pattern remains relatively stable.

The projected growth is consistent with Balamakin and Osan (2025), who also found a continuing increase in the projected HDI of East Nusa Tenggara Province using Brown's Double Exponential Smoothing.

Although the study areas and smoothing procedures differ, both studies indicate that DES can capture the long-term growth pattern of HDI data. Nevertheless, direct comparisons of forecast values should be avoided because each region has different socioeconomic conditions, initial HDI levels, observation periods, and development dynamics.

Policy Implications and Research Limitations

The projected increase provides useful quantitative information for regional development planning. The transition toward the very high HDI category will require sustained improvements across all HDI dimensions rather than reliance on statistical trends alone. In the health dimension, policy priorities may include improving the accessibility and quality of healthcare services, particularly for remote communities and vulnerable groups. In the education dimension, maintaining school participation, improving educational quality, and expanding equitable access should remain important priorities. Improvements in living standards may be supported through employment creation, local economic development, and the strengthening of micro, small, and medium enterprises.

The forecast should be used as a supporting instrument for planning and evaluation rather than as a deterministic target. The Holt model uses only historical HDI values and does not explicitly incorporate economic growth, poverty, public expenditure, demographic changes, healthcare access, educational outcomes, or government policy interventions. Unexpected shocks and changes in the HDI calculation methodology may also cause future observations to differ from the projected values. In addition, the absence of prediction intervals means that the uncertainty surrounding the point forecasts has not been quantified.
Overall, Holt's Double Exponential Smoothing produced a close fit to the historical HDI series based on the reported error measures and generated a gradual upward projection for 2026–2030. The model provides a straightforward description of the expected direction of HDI development, but its results must be interpreted with consideration of data consistency, possible structural changes, in-sample evaluation, and external factors not represented in the model.

CONCLUSION

This study successfully modeled and forecasted the Human Development Index (HDI) of Toba Regency using Holt's *Double Exponential Smoothing*. The optimal smoothing parameters were $\alpha = 0.96$for the level component and $\beta = 0.05$for the trend component. The model produced relatively low forecasting errors, with a MAD of 0.57, an RMSE of 1.34, and a MAPE of 0.77%. These values indicate a close *in-sample* fit between the estimated and historical HDI values. The forecasts show a gradual increase from 79.60 in 2026 to 81.37 in 2030, with Toba Regency projected to move from the high HDI category to the very high category in 2027. Nevertheless, these results represent statistical projections rather than certain future outcomes because the model relies exclusively on historical HDI patterns and does not explicitly incorporate economic conditions, demographic changes, government policies, or developments in health and education. Therefore, the forecasts should be used as supporting information for regional planning and policy evaluation. Future research should apply *out-of-sample* validation, provide prediction intervals, verify the substantial change in the data around 2014, and compare Holt's method with alternative forecasting models to obtain more robust projections.

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