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# PERFORMANCE COMPARISON OF SOME TYPES OF WAVELET TRANSFORMS FOR TOURISM DATA PATTERN APPROXIMATION

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*ABSTRACT*

*Tourism is an economic sector that significantly supports the country's foreign exchange, including in West Nusa Tenggara Province (NTB). Data on tourist visits to an area, including to NTB, is a representation of time series data. The wavelet method is one of the tools that is quite reliable for modeling time series data. This study aims to model the number of tourist visits to NTB Province using discrete wavelet transformation decomposition to estimate data. Several Wavelet functions such as Haar wavelet, Symlet, Coiflet, Daubechies, Best-localized Daubechies, Fejér-Korovkin, and Bi-orthogonal Splines at various orders and levels of decomposition became the basis for simulation in modeling data. Based on the Root of Mean of Square Error (RMSE) indicator, this study compares the performance of each wavelet function against the modeling performance at various orders and levels of decomposition. Numerically, for the data on the total number of tourists visiting NTB Province, the best approximation was given by the Fejér-Korovkin wavelet order 4-th (fk4) and the best-localized Daubechies wavelet order 7-th (bl7) at the 2-nd level with an RMSE value of $2.2993 \times 10^{-11}$. Partially, the best approximation of the data on the number of foreign tourist visits was given by the Bi-orthogonal Splines wavelet type order 2.6 (bior2.6) at the 2nd decomposition level with an RMSE value of $1.1718 \times 10^{-11}$ and for the data on domestic tourist visits was given by the Fejér-Korovkin wavelet type order 4-th (fk4) and the best-localized Daubechies wavelet order 7-th (bl7) at the 2nd level with an RMSE value of $1.3352 \times 10^{-11}$.*

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## 1. INTRODUCTION

The tourism sector is one of the national Areas; and has a variety of tourist attractions, such as natural, coastal, and marine tourism, religion and culture, as well as national parks and historical sites. Lombok's natural panorama consists of beautiful beaches, stunning coral reef tourism, and quality handicraft tourism such as pearl jewelry, bamboo crafts, and nautilus. In addition, various cultural attractions and tourism are rich in cultural value, historical sites, and Mount Rinjani National Park which has been declared as one of the World Geopark sites.

Before the COVID-19 pandemic, Lombok was a destination area with significant development. The number of tourists visiting NTB increased from 1,357,602 people in 2013 and reached a peak in 2017 of 3,508,903 people. NTB Province is recorded as occupying the 18th position of tourist destinations throughout Indonesia, apart from the decline in tourist visits in 2018 due to the earthquake disaster and further exacerbated by the outbreak of the Covid-19 Pandemic so that at the end of 2021 the number of tourists was 875,773 [1]. Positive factors emerged at the end of 2021 with the holding of the 2021 Mandalika World Superbike (WSBK) and continued with the 2022 and 2023 MotoGP. These two international activities and supported by the National and Provincial Programs of NTB to increase the number of tourist visits to NTB and Lombok Provinces, especially to be a supporting capacity and a positive stimulant for the rise of tourism in Lombok.

The new normal situation at the end of 2021 has given the tourism sector a breath of fresh air. Several tourist attractions are starting to improve and are ready to receive visits from tourists. On the other hand, travel and tourist travel businesses are starting to go to normal. In Lombok, this positive factor was strengthened by the holding of the 2021 WSBK international event and the 2022 and 2023 MotoGP [1]. The new normal, various international events, and the uniqueness and beauty of tourism resources on Lombok Island and Sumbawa Island are believed to provide a positive stimulus to the number of tourist visits to NTB Province, both domestic and foreign tourists. To face and provide the best service to this source of foreign exchange, the government, both nationally and in NTB Province, needs to prepare its supporting facilities and infrastructure. In planning tourism support facilities and infrastructure, the government will be more optimal if the pattern/model of the number of tourist visits to NTB Province is known. Therefore, research with a focus on modeling and forecasting the pattern of tourist visits to NTB Province is very necessary and important to be carried out.

The development of time series data analysis methods and techniques is in line with the development of science and technology. The limitations of statistical models related to the requirements that are met by the data to be driven such as stationary, the errors must be normally distributed, free of collinearity, and so on, are why some researchers turn to soft computing techniques. Since the 1990s, soft computing techniques such as neural networks (NNs), fuzzy techniques, and wavelets have been used as alternative models in time series analysis [2], [3] .

Research related to the modeling of tourist visits with different loci has been carried out, including Li et al. [4] discusses tourism forecasting models based on internet media such as search engines, web traffic, social media, and multiple sources; Park et al. [5] discusses the forecasting model of tourist data obtained online visiting Hong Kong using the SARIMA/SARIMAX method and the Exponential Smoothing State Space (ETS) method; Wu-Bi et al. [6] discussed tourist forecasting using the deep learning time series method. Then Xie et al. [7] discussed the forecasting of tourist visits by sea to China using *big data* with a machine learning approach; Akin [8] talked about several methods to forecast tourist visits to Turkey including Seasonal Auto-Regressive Integrated Moving Average *(*SARIMA*),* n-Support Vector Regression, and multi-layer perceptron type Neural Network models; Santamaria and Filis [9] discuss the relationship between the tourism model and economic growth in Spain. Domestically, several researchers have also published foreign tourist visits in the Riau Islands using the transfer function model; Susila [10] discusses the multivariate modeling of foreign tourist visits to Indonesia through air, sea, and land doors involving the impact of the Covid-19 outbreak; Pratama et al. [11] and Julianto et al. [12] discusses the prediction of the number of tourist visits using the Regression and ARIMA models as well as the ARIMAX and SARIMAX models; Lakuhati et al. [13] discusses the factors that affect tourist visits to the Ecotourism Area in Bahoi Village, North Minahasa; and Kencana and Damayanti [14] discuss the structural analysis of the model of tourist return visits to Badung, Bali.

Regarding the problem of modeling and forecasting time series data in economics and tourism, Li et al. [15] have successfully created a model for forecasting tourist arrivals based on denoising techniques and potential factors. Mariani et al. [16] conducted a market stock analysis using the dynamic Fourier transformation and wavelet techniques. Their results show that the model obtained is effective in terms of the characterization of market stock data so that it can be the basis for decision-making related to market stocks. Another study conducted by Bayih & Singh [17] that the model obtained can describe the motivation and habitual behavior of tourists. Meanwhile, Osu et al. [18] also successfully modeled and analyzed international market behavior using the wavelet method. By another method, Montano et al. [19] The resulting model can estimate the stay time of tourism based on a regression model. Novita et al. [20] predict the number of international tourists visiting East Java by comparing the K-Nearest Neighbor and Neural Network models. Furthermore, Brida et al. [21] using a nonlinear approximation approach were able to model the total tourist expenditure in the cruise tourist city in Uruguay.

Referring to the advantages of the wavelet method above, this study uses the wavelet method to model the number of tourists visiting NTB Province. The results of this research are expected to produce a model that can describe the pattern of tourist arrivals to NTB, so that it can be the foundation or basis for related parties, including the NTB Provincial government, in managing and planning the development of tourism sector in NTB Province.

## 2. RESEARCH METHODS

This section discusses wavelet methods consisting of wavelet transforms and several types of wavelets, and research variables and data sources.

### 2.1 Wavelet Transform

Wavelet transformation is a transformation process of a signal or time series data with the procedure as shown in Figure 1. The Continuous Wavelet Transform (CWT), $Wf(u,s)$ from a signal$f(t)$, on an $s$ scale, and the position of $u$ is calculated based on the Equation (1) [22]-[23]:

$$Wf(u,s) = \int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{s}}\Psi^*\left(\frac{t-u}{s}\right)dt \tag{1}$$

Suppose $f(n)$ is a discrete function defined in $[1, M-1]$. The Discrete Wavelet Transform (DWT) of a signal$f(n)$ is given by the following Equation (2) [22]:

$$f(n) = \frac{1}{\sqrt{M}}\sum_k W_\varphi\,(j_0,k)\varphi_{j_0,k}(n) + \frac{1}{\sqrt{M}}\sum_{j=j_0}^{\infty}\sum_k W_\psi(j,k)\psi_{j,k}(n) \tag{2}$$

with $W_\varphi(j_0,k)$ and $W_\psi(j,k)$ each expresses the approximation coefficient and detail of the function $f(n)$ with the formula

$$W_\varphi(j_0,k) = \frac{1}{\sqrt{M}}\sum_{n=0}^{M-1} f(n)\varphi_{j_0,k}(n) \tag{3}$$

and

$$W_\psi(j_0,k) = \frac{1}{\sqrt{M}}\sum_{n=0}^{M-1} f(n)\psi_{j,k}(n)\,, j \geq j_0 \tag{4}$$

Furthermore, if $\alpha$ state the dilatation parameters and $\tau$state the translation parameters of the mother Wavelet $\Psi(t)$ , it $\Psi_{\alpha,\tau}(t)$ can be formulated as Equation (5).

$$\Psi_{\alpha,\tau}(t) = \frac{1}{\sqrt{\alpha}}\Psi\left(\frac{t-\tau}{\alpha}\right) \tag{5}$$

On the other hand, wavelets $\Psi(t)$ can be reported as a linear combination of the scale version and the shift of the scale function $\varphi(t)$, known as the Father Wavelet, given by Equation (6).

$$\Psi(t) = \sum_{n\in\mathbb{Z}} h_1(n)\varphi(2t-n) \tag{6}$$

where the coefficient $h_1(n)$ is the coefficient of the high-pass filter, and the scale function $\varphi(t)$ is given by Equation (7),

$$\varphi(t) = \sum_{n\in\mathbb{Z}} h_0(n)\varphi(2t-n) \tag{7}$$

and the coefficient $h_0(n)$ is the coefficient of the low-pass filter [22].

Suppose a signal (time series data) $X[n]$is given. The signal decomposition process $X[n]$ is carried out by dividing the signal into 2 (two) parts, namely the low-pass coefficient $h_0$ (approximation coefficient) and the high-pass coefficient $h_1$ (detail coefficient) as in Figure 1. Furthermore, the decomposition results undergo a decimation process using a downsampling operator. After passing through the decimation process, the signal is reconstructed using the convulsion operator into a low-pass synthesis coefficient $h'_0$and a high-pass filter coefficient $h'_1$, and further reconstructed into a signal $X'[n]$ [23].

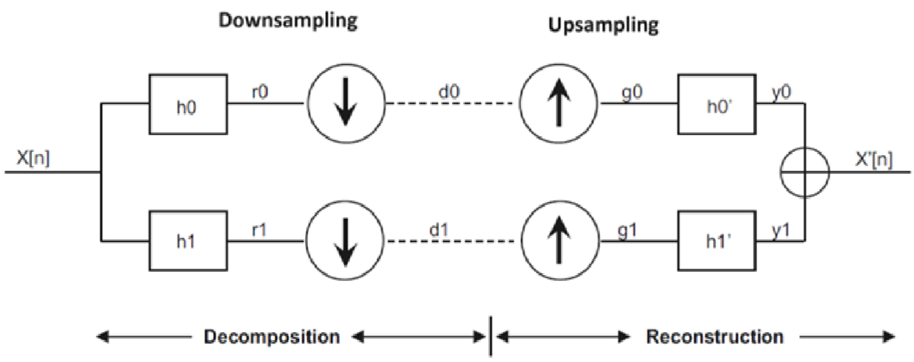



**Figure 1. The Process of Decomposition of Signals$X[n]$ and Reconstruction into $X'[n]$**
**Source: Akujuobi** [23].

### 2.2 Wavelet Types

The wavelet transform depends on the wavelet function base. The type of wavelet function is differentiated based on some characteristics including orthogonality, support width, filter length, regularity, symmetry, number of vanishing moments of father wavelets, and the scope of application. Some types of wavelets that are often used include Haar wavelets, Symlets, Daubechies, Coiflets, best-localized Daubechies, Fejér-Korovkin, and Wavelet Biorthogonal Splines with characteristics given in Table 1 ([24], [25], [26])

**Table 1. Some Types and Characteristics of Wavelets**

| Wavelet Type | Haar | Symlets (Order N) | Coiflets (Order N) | Daubechies (Order N) | Best-localized Daubechies (Order N) | Fejér-Korovkin (Order N) | Biorthogonal Splines, (Nr order rec., Nd order dec.) |
|---|---|---|---|---|---|---|---|
| **Notation** | haar | symN | coifN | dbN | bl.N | fkN | biorNr.Nd |
| **Orthogonal** | Yes | Yes | Yes | Yes | Yes | Yes | No |
| **Biorthogonal** | Yes | Yes | Yes | Yes | No | No | Yes |
| **Width** | Yes | Yes | No | Yes | Yes | Yes | Yes |
| **Support Compact** | 1 | 2N-1 | - | 2N-1 | - | - | 2Nr+1 (rec.)<br>2Nd+1 (dec.) |
| **Filter length** | 2 | 2N | 6N | 2N | 2N | - | max(2Nr, 2Nd) + 2 |
| **Regularity** | Not continuous | - | - | $\pm 0.2$ N for large N | - | - | Nr-1, and Nr-2 (at psi rec. kNots) |
| **Symmetry** | Yes | Near | - | Far | - | - | Yes |
| **Num. of Vanish. moment** | 0 | N | 2N | N | N | - | Nr, for psi dec. |
| **DWT & CWT Implementation** | possible | possible | possible | possible | DWT only | possible | possible |

### 2.3 Research Variables and Data Sources

This study compares tourism data patterns using several wavelet transformations from several types of wavelets, namely Haar wavelets, Symlets, Daubechies, Coiflets, best-localized Daubechies, Fejer-Kerovin, and Wavelet Biorthogonal Splines. The performance comparison of each wavelet is based on the root of the mean square of error (RMSE) value. The data used in this study is monthly data on the number of tourist visits to West Nusa Tenggara Province (NTB), which consists of the number of domestic and foreign tourist visits. Data was obtained from the Central Statistics Agency (BPS) of NTB for the period January 2008 – December 2022 [27].

## 3. RESULTS AND DISCUSSION

### 3.1 Description of NTB Tourism

NTB Province is supported by 10 districts/cities and consists of 2 relatively large island clusters, namely Sumbawa Island and Lombok Island with 3 main tribes, namely the Sasak, Samawa, and Mbojo. Besides the two large islands, NTB has hundreds of small island clusters that are inhabited or not. Tourism in NTB is supported by natural and cultural tourism such as natural, beach, and marine tourism, religion, and culture, as well as national parks and historical sites on Sumbawa Island and Lombok Island. The natural panorama consists of beautiful and beautiful beaches, stunning coral reef tours, and *quality* handicraft tours such as pearl jewelry, bamboo crafts, and nautilus. In addition, various attractions and cultural tourism are rich in cultural value, historical sites, and Mount Tambora and Mount Rinjani National Parks. In particular, Mount Rinjani National Park has been declared as one of the World Geopark sites ([1], [27], [28]).

**Table 2. The Statistics of the Number of Tourists Visiting NTB Province from January 2008 to December 2022**

| Statistics Data | Total of Tourists | Foreign Tourists | Domestic Tourists |
|---|---|---|---|
| Mean | 140291 | 54137 | 86154 |
| Maximum | 544237 | 271197 | 352087 |
| Minimum | 2610 | 70 | 2465 |

With these various attractions, tourist visits to NTB Province have increased significantly and reached a peak around 2017. However, natural disasters in 2018 in the form of an earthquake that hit Lombok Island and the Covid-19 pandemic became a negative factor so the number of visits decreased from early 2020 to mid-2022. Furthermore, after the ban and travel restrictions due to the Covid-19 pandemic were lifted, tourist visits to NTB Province began to climb again as provided by **Figure 1** with statistical data provided in **Table 2**.

Approximation of tourism data using wavelets transform in this study, the estimation of monthly data patterns of tourist visits to NTB Province for the period January 2008 to December 2022 uses a wavelet transformation tool. Some of the types of wavelets used as transformation bases are Haar wavelets, Daubechies, Symlets, Coiflets, bi-orthogonal splines, best-localized Daubechies, and Fejér-Korovkin wavelets at various orders and levels of decomposition.

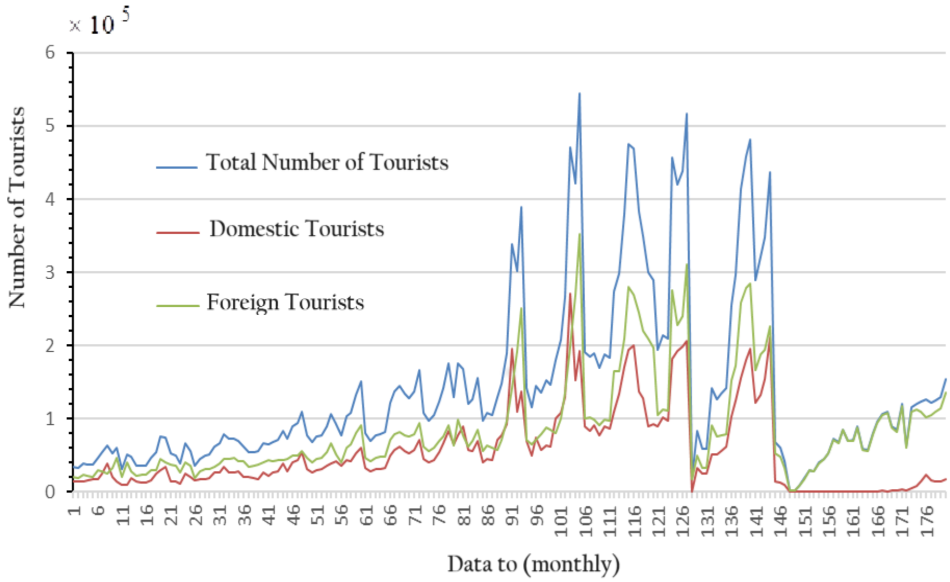



**Figure 1. Number of Tourists (Monthly) Visiting NTB Province from January 2008 to December 2022**

### 3.2 Haar Wavelet

The estimation of the data pattern of tourist visits to NTB Province based on the Haar wavelet at various levels, namely levels 2, 3, 4, 5, 6, and 8, was simulated. Based on the root of the mean of square error (RMSE) indicator, it is produced that the data pattern using wavelet transformations with the basis of the Haar function is quite good, as given in **Table 3**.

**Table 3** shows that the performance of estimation based on the RMSE indicator on tourist visit data to NTB Province using the Haar wavelet transformation as its basis at various levels (2, 3, 4, 5, 6, and 8) gives quite good results. The best approximation performance using the Haar wavelet transformation was given by level 2 with RMSE values of 2.3813$\times 10^{-11}$, 3.4908$\times 10^{-11}$, and 5.2687$\times 10^{-11}$respectively for foreign tourists, domestic tourists, and total tourists visiting NTB Province. Graphically, the best approximation using Haar wavelet transformation is given in **Figure 2** (a).

**Table 3. Performance of Approximation Tourism Data of NTB Province using Haar Wavelets Transform Based on RMSE Indicator**

| Level of Haar Wavelet Decompositions | Performance of Approximation Based on RMSE | | |
|---|---|---|---|
| | Foreign Tourists ($\times 10^{-11}$) | Domestic Tourists ($\times 10^{-11}$) | Total Number of Tourist ($\times 10^{-11}$) |
| **2** | **2.3813** | **3.4908** | **5.2687** |
| 3 | 3.4512 | 4.8194 | 7.0935 |
| 4 | 4.7216 | 6.1153 | 1.0504 |
| 5 | 5.9876 | 7.0845 | 12.357 |
| 6 | 6.0059 | 8.7627 | 13.134 |
| 8 | 6.2949 | 11.771 | 20.670 |
| **Minimum of RMSE** | **2.3813** | **3.4908** | **5.2687** |

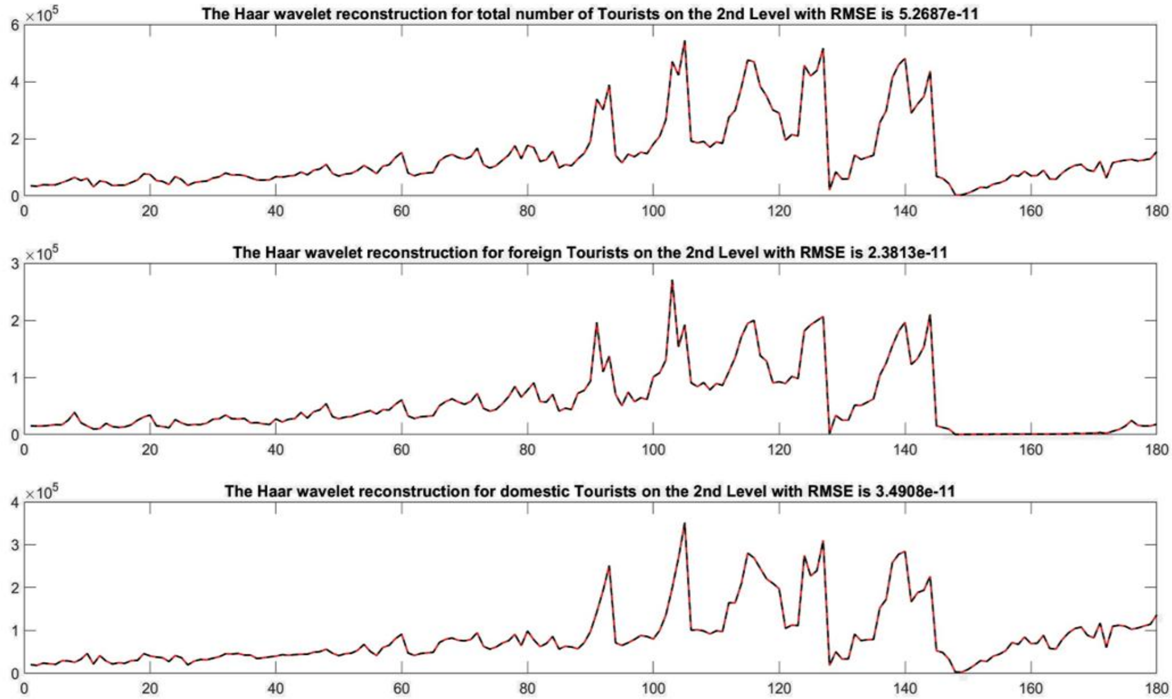
### 3.3 Symlets Wavelet

The approximation of the data pattern of tourist visits to NTB Province based on Symlets wavelet is simulated at various levels, namely levels 2, 3, 4, 5, 6, and 8. Based on the root of the mean of square error (RMSE) indicator, it was produced that the approximation of the data pattern of the number of tourist visits to NTB using a wavelet transformation based on the Symlets function gave quite good approximation results, as given by **Table 4**.

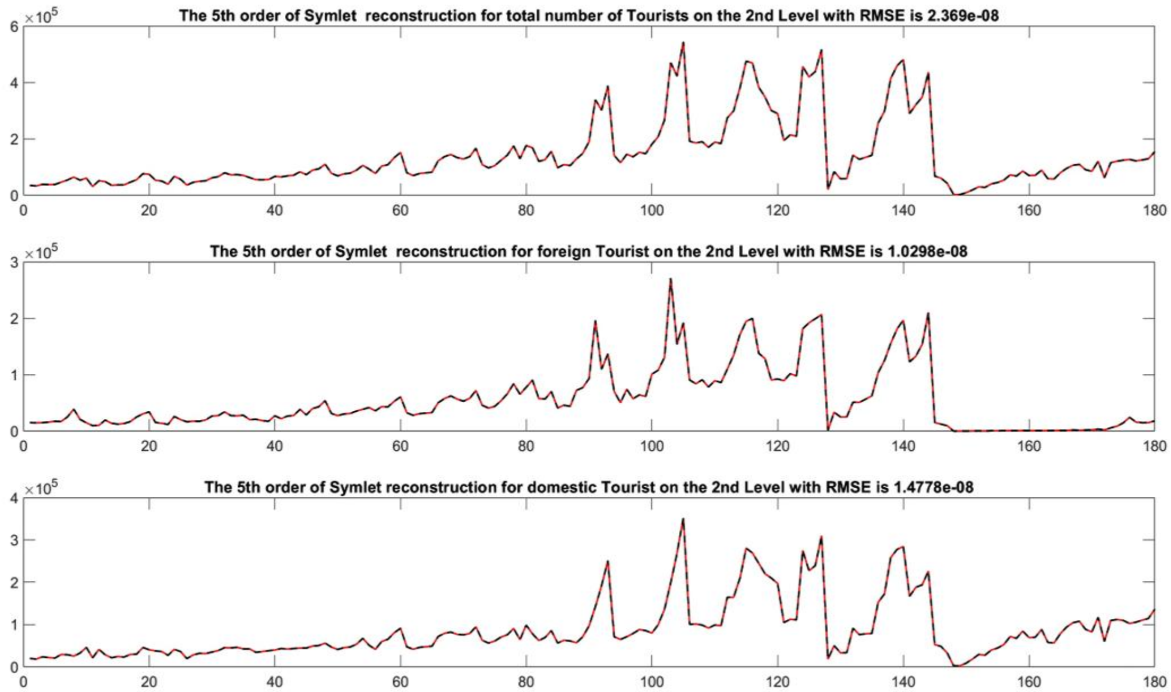
**Table 4.** **Performance of Approximation Tourism Data of NTB Province using the *n*-th order Symlets Wavelets Transform Based on RMSE Indicator, *n* = 2, 3, 4, 5, 6, and 8**

| The Order of Symlets | Level of Wavelets Decomposition | Performance of Approximation Based on RMSE | | |
|---|---|---|---|---|
| | | Foreign Tourists $(\times 10^{-8})$ | Domestic Tourists $(\times 10^{-8})$ | Total Number of Tourists $(\times 10^{-8})$ |
| 2 | 2 | 3.6420 | 5.0602 | 8.3602 |
| | 3 | 5.4202 | 7.4874 | 12.573 |
| | 4 | 5.9681 | 8.1906 | 13.810 |
| | 5 | 6.6594 | 8.9185 | 15.210 |
| | 6 | 8.1371 | 9.8520 | 17.549 |
| | 8 | 11.648 | 11.930 | 22.816 |
| **Minimum of RMSE of 2nd Order** | | 3.6420 | 5.0602 | 8.3602 |
| 3 | 2 | 46.414 | 63.812 | 107.940 |
| | 3 | 61.917 | 86.503 | 145.720 |
| | 4 | 76.280 | 107.890 | 180.910 |
| | 5 | 92.529 | 114.850 | 202.300 |
| | 6 | 112.670 | 125.600 | 231.340 |
| | 8 | 127.240 | 161.220 | 279.380 |
| **Minimum of RMSE of 3rd Order** | | 46.414 | 63.812 | 107.940 |
| 4 | 2 | 2.9902 | 4.2801 | 6.8675 |
| | 3 | 4.7689 | 6.5081 | 10.9750 |
| | 4 | 5.3562 | 7.4335 | 12.5020 |
| | 5 | 5.6829 | 8.1532 | 13.5190 |
| | 6 | 6.9387 | 8.8777 | 15.4480 |
| | 8 | 8.7578 | 9.8727 | 18.0580 |
| **Minimum of RMSE of 4th Order** | | 2.9902 | 4.2801 | 6.8675 |
| **5** | **2** | **1.0298** | **1.4778** | **2.3690** |
| | 3 | 1.6508 | 2.2299 | 3.7727 |
| | 4 | 1.8021 | 2.4433 | 4.1408 |
| | 5 | 1.8940 | 2.6153 | 4.3963 |
| | 6 | 2.2954 | 2.8832 | 5.0603 |
| | 8 | 3.0758 | 3.2876 | 6.1828 |
| **Minimum of RMSE of 5th Order** | | 1.0298 | 1.4778 | 2.3690 |
| 6 | 2 | 4.5699 | 6.5632 | 10.5160 |
| | 3 | 7.0463 | 9.8356 | 16.3740 |
| | 4 | 7.7803 | 1.0.908 | 18.1750 |
| | 5 | 8.3828 | 12.0360 | 19.8540 |
| | 6 | 10.5370 | 13.3000 | 23.2040 |
| | 8 | 13.7130 | 1.5.2370 | 28.0420 |
| **Minimum of RMSE of 6th Order** | | 4.5699 | 6.5632 | 10.5160 |
| 8 | 2 | 1.4787 | 2.0051 | 3.4049 |
| | 3 | 1.7932 | 2.3672 | 4.0597 |
| | 4 | 2.0214 | 2.7636 | 4.6678 |
| | 5 | 2.4963 | 2.9385 | 5.3075 |
| | 6 | 2.6594 | 3.0061 | 5.5100 |
| | 8 | 2.9499 | 3.2160 | 5.9610 |
| **Minimum of RMSE of 8th Order** | | 1.4787 | 2.0051 | 3.4049 |

Meanwhile, a comparison graph between the best approximator in this case, the sym5 transform at level 2, and the actual data is provided in Figure 2 (b). In the case of the number of foreign tourist visits, the best approximation performance was obtained as an RMSE value of $\mathbf{1.0298} \times 10^{-8}$**,** in the case of the number of domestic tourist visits, the best approximation performance was obtained as in RMSE value of $\mathbf{1.4778} \times 10^{-8}$, and case of the total number of the tourist visits the best approximation performance was obtained RMSE value of $\mathbf{2.3690} \times 10^{-8}$.




**(a)**




**(b)**

**Figure 2. The Comparative Graph of the Reconstruction Results using (a) the 2nd level of Haar Wavelets and (b) the 2nd Level of the 5th Order of Symlets Wavelets with Actual Data of Each Classification of Tourist Data Visiting NTB Province in January 2008 – December 2022.**

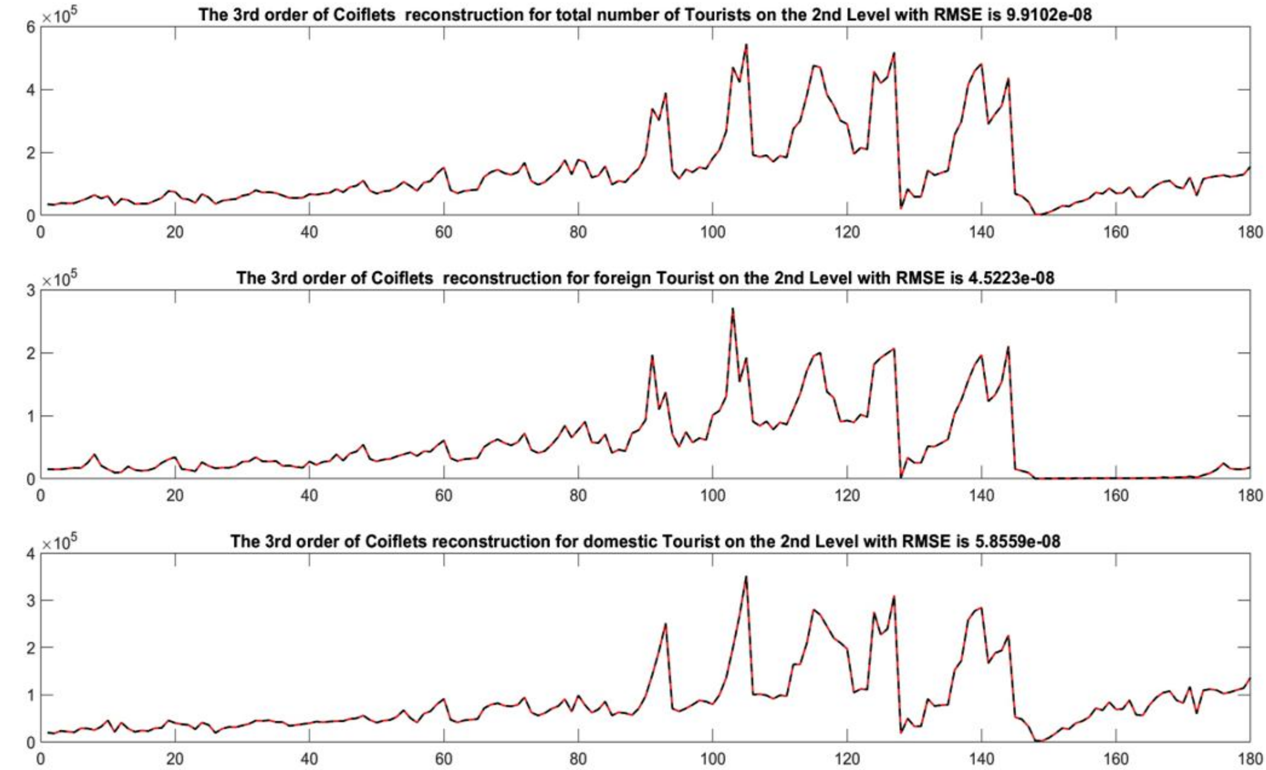
### 3.4 Coiflets Wavelet

The estimation of the data pattern of tourist visits to NTB Province based on wavelet Coiflets is simulated at various levels, namely levels 2, 3, 4, and 5. Unlike other types of Wavelets, decomposition at levels 6 and 8 cannot be simulated. Based on the root of the mean of square error (RMSE) indicator, it was produced that the estimation of the data pattern of the number of tourist visits to NTB using a wavelet transform based on the Coiflets function gave quite good approximation results, as given by **Table 5**.

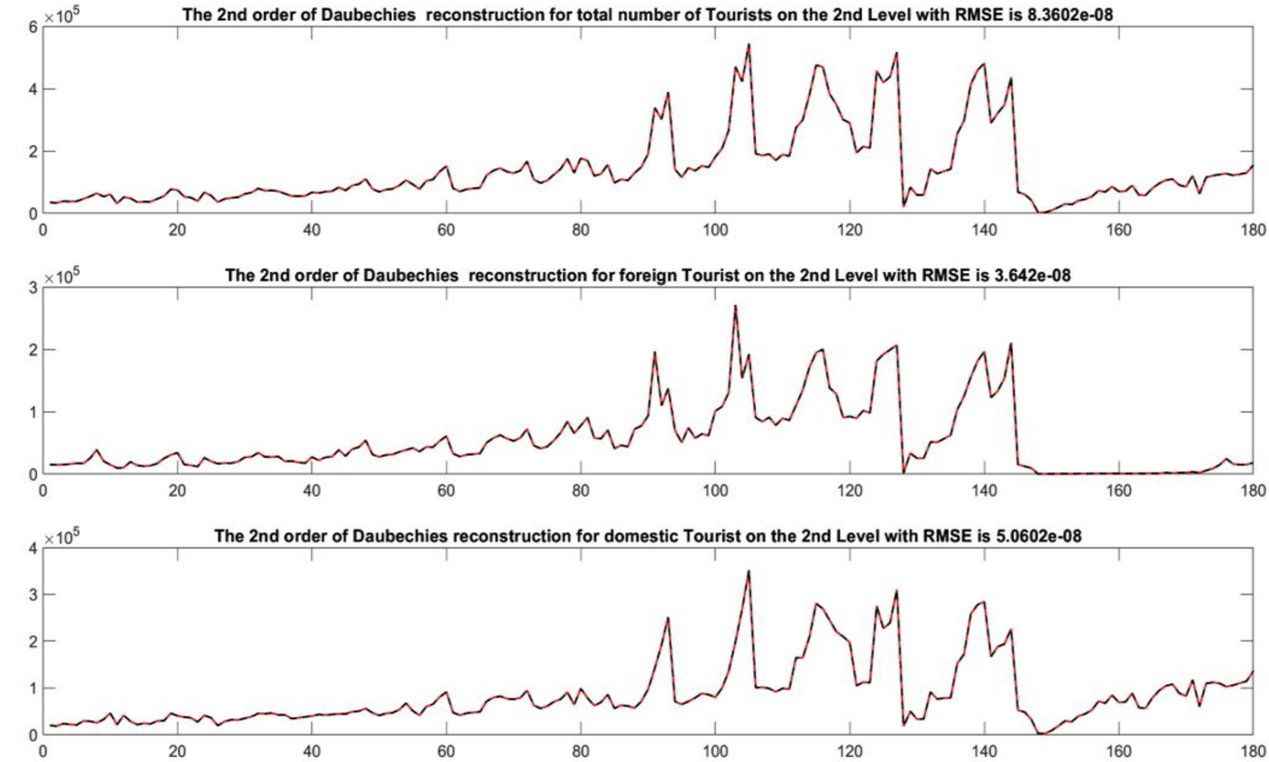
The best approximator resulting from the Coiflets wavelet transformation is given by **the coif3** approximator at level 2. The comparison graph between **coif5** level 2 and the actual data is presented in **Figure 3** (a). In the case of the number of foreign tourist visits, the best approximation performance was obtained RMSE value of $\mathbf{4.5223} \times 10^{-8}$**,** and in the case of the number of domestic tourist visits, the best approximation performance was obtained RMSE value of $\mathbf{5.8559} \times 10^{-8}$**,** and in the case of the total number of tourist visits, the best approximation performance was obtained RMSE value of $\mathbf{9.9102} \times 10^{-8}$.

**Table 5. Performance of Approximation Tourism Data of NTB Province using the *n*-th Order Coiflets Wavelets Transform based on RMSE Indicator, *n* = 2, 3, 4, and 5.**

| The Order of Coiflets | Level of Wavelets Decomposition | Performance of Approximation Based on RMSE | | |
|---|---|---|---|---|
| | | Foreign Tourists ($\times 10^{-8}$) | Domestic Tourists ($\times 10^{-8}$) | Total Number of Tourists ($\times 10^{-8}$) |
| 2 | 2 | 69.766 | 96.369 | 160.63 |
| | 3 | 106.160 | 140.820 | 241.48 |
| | 4 | 118.800 | 158.91 | 271.54 |
| | 5 | 135.180 | 175.70 | 303.55 |
| | 6 | 164.570 | 193.12 | 349.35 |
| | 8 | 207.740 | 220.83 | 415.40 |
| Minimum of RMSE of 2nd Order | | 69.766 | 96.369 | 160.63 |
| **3** | **2** | **4.5223** | **5.8559** | **9.9102** |
| | 3 | 6.9688 | 8.7950 | 15.387 |
| | 4 | 7.5387 | 9.7868 | 16.959 |
| | 5 | 7.7533 | 9.9858 | 17.353 |
| | 6 | 7.7186 | 10.0350 | 17.363 |
| | 8 | 7.6792 | 10.0070 | 17.281 |
| Minimum of RMSE of 3rd Order | | 4.5223 | 5.8559 | 9.9102 |
| 4 | 2 | 164.50 | 230.30 | 373.09 |
| | 3 | 234.16 | 313.19 | 529.36 |
| | 4 | 245.64 | 327.30 | 555.01 |
| | 5 | 248.04 | 329.34 | 559.28 |
| | 6 | 249.27 | 330.08 | 5.60.86 |
| | 8 | 255.01 | 334.25 | 567.65 |
| Minimum of RMSE of 4th Order | | 164.50 | 230.30 | 373.09 |
| 5 | 2 | 31377 | 44803 | 71542 |
| | 3 | 39571 | 56235 | 91810 |
| | 4 | 42001 | 59017 | 97045 |
| | 5 | 42305 | 59463 | 97816 |
| | 6 | 42595 | 59612 | 98184 |
| | 8 | 44375 | 60121 | 100220 |
| Minimum of RMSE of 5th Order | | 31377 | 44803 | 71542 |




**(a)**




**(b)**

**Figure 3. The Comparative Graph of the Reconstruction Results using (a) The 2nd Level of the 3rd Order of Coiflets Wavelets and (b) the 2nd Level of the 2nd Order of Daubechies Wavelets with Actual Data for each Classification of Tourist Data Visiting NTB Province for the Period January 2008 – December 2022.**

**Table 6. Performance of Approximation Tourism Data of NTB Province using the *n*-th order Daubechies wavelets transform based on RMSE Indicator, *n* = 2, 3, 4, 5, 6, and 8.**

| The Order of Daubechies | Level of Wavelets Decomposition | Performance of Approximation Based on RMSE | | |
|---|---|---|---|---|
| | | Foreign Tourists ($\times 10^{-8}$) | Domestic Tourists ($\times 10^{-8}$) | Total Number of Tourists |
| **2** | **2** | **3.6420** | **5.0602** | **8.3602** |
| | 3 | 5.4202 | 7.4874 | 12.573 |
| | 4 | 5.9681 | 8.1906 | 13.810 |
| | 5 | 6.6594 | 8.9185 | 15.210 |
| | 6 | 8.1371 | 9.8520 | 17.549 |
| | 8 | 11.648 | 1.1930 | 22.816 |
| Minimum of RMSE of 2nd Order | | 3.6420 | 5.0602 | 8.3602 |
| 3 | 2 | **46.414** | **63.812** | **107.94** |
| | 3 | 61.917 | 86.503 | 145.72 |
| | 4 | 76.280 | 107.89E | 180.91 |
| | 5 | 92.529 | 114.85 | 202.30 |
| | 6 | 112.67 | 125.60 | 231.34 |
| | 8 | 127.24 | 161.22 | 279.38 |
| Minimum of RMSE of 3rd Order | | 46.414 | 63.812 | 107.94 |
| 4 | 2 | **8.2333** | **11.364** | **19.159** |
| | 3 | 11.367 | 15.193 | 26.017 |
| | 4 | 1..065 | 17.526 | 29.946 |
| | 5 | 16.136 | 19.417 | 34.687 |
| | 6 | 19.397 | 21.433 | 39.625 |
| | 8 | 21.399 | 25.837 | 45.206 |
| Minimum of RMSE of 4th Order | | 8.2333 | 11.364 | 19.159 |
| 5 | 2 | **11.150** | **15.426** | **25.926** |
| | 3 | 15.877 | 21.812 | 36.871 |
| | 4 | 20.230 | 26.694 | 45.932 |
| | 5 | 24.753 | 30.089 | 53.481 |
| | 6 | 28.864 | 34.213 | 61.381 |
| | 8 | 36.497 | 42.415 | 76.282 |
| Minimum of RMSE of 5th Order | | 1.1.150 | 15.426 | 25.926 |
| 6 | 2 | **6.8777** | **9.7343** | **16.199** |
| | 3 | 8.0174 | 10.924 | 18.460 |
| | 4 | 10.751 | 14.081 | 24.388 |
| | 5 | 14.161 | 15.262 | 28.708 |
| | 6 | 16.512 | 17.242 | 32.633 |
| | 8 | 20.876 | 2..112 | 43.726 |
| Minimum of RMSE of 6th Order | | 6.8777 | 9.7343 | 16.199 |
| 8 | 2 | **19.581** | **26.884** | **45.355** |
| | 3 | 27.345 | 37.386 | 63.384 |
| | 4 | 33.128 | 44.141 | 75.667 |
| | 5 | 40.547 | 49.035 | 87.501 |
| | 6 | 47.344 | 54.039 | 98.552 |
| | 8 | 58.166 | 64.245 | 118.42 |
| Minimum of RMSE of 8th Order | | 19.581 | 26.884 | 45.355 |

### 3.5 Daubechies Wavelet

The approximation of the data pattern of tourist visits to NTB Province based on the Daubechies wavelet was simulated at various levels, namely levels 2, 3, 4, 5, 6, and 8. Based on the root of the mean of square error (RMSE) indicator, it is produced that the approximation of the data pattern of the number of tourist visits to NTB using a wavelet transformation based on the Daubechies function provides the RMSE value for the performance indicator of the ability to approximate as given by Table 6.

The best approximator resulting from the Coiflets wavelet transformation is given by the db2 approximator at level 2. The comparison graph between db2 level 2 and the actual data is presented in Figure 3 (b). In the case of the number of foreign tourist visits, the best approximation performance was obtained RMSE value of **3.6420**$\times 10^{-8}$**,** and in the case of the number of domestic tourist visits, the best approximation performance was obtained RMSE value of **5.0602**$\times 10^{-8}$**,** and in the case of the total number of tourist visits, the best approximation performance was obtained RMSE value of **8.3602**$\times 10^{-8}$.

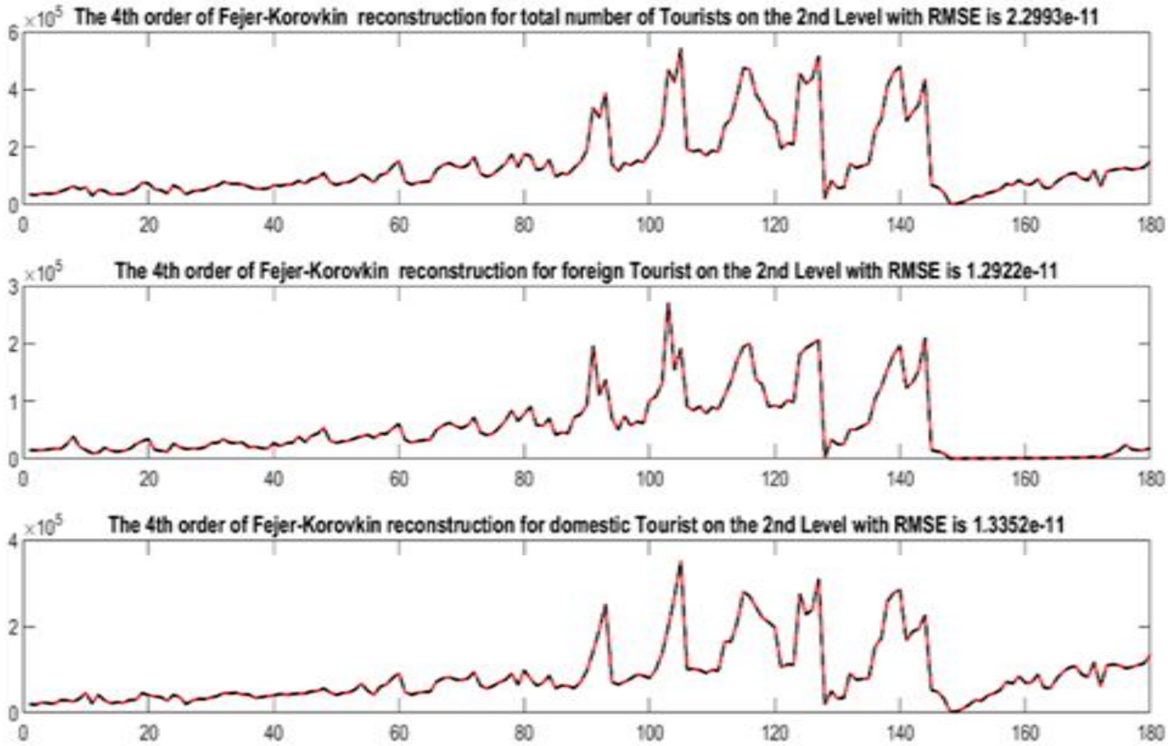
### 3.6 Fejér-Korovkin Wavelet

The approximation of the data pattern of tourist visits to NTB Province based on the Fejér-Korovkin wavelet was simulated at various levels, namely levels 4, 6, and 8. Based on the RMSE indicator, it is produced that the approximation of the data pattern of the number of tourist visits to NTB using a wavelet transformation with the basis of the Fejér-Korovkin function provides the RMSE value for the performance indicator of the ability to estimate as given by Table 7.

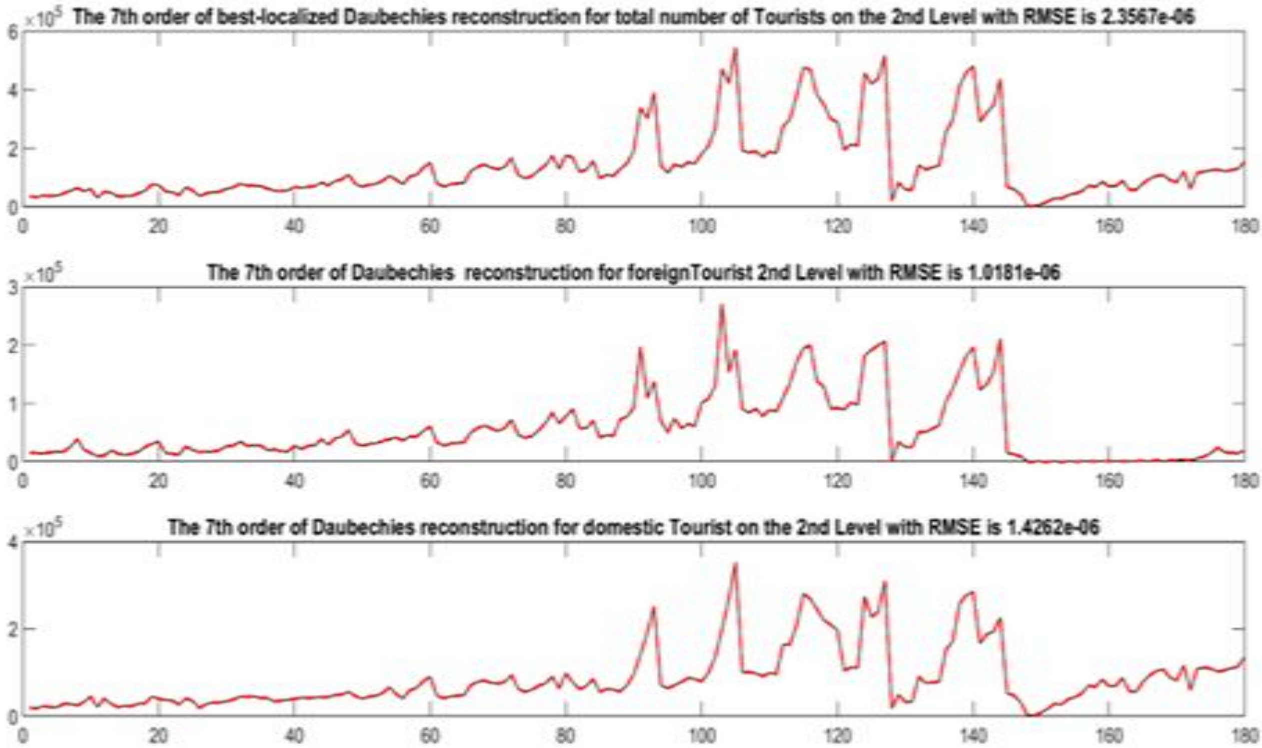
**Table 7. Performance of Approximation Tourism Data of NTB Province using the *n*-th order Fejér-Korovkin Wavelets Transform Based on RMSE indicator, *n* = 4, 6, and 8.**

| The Order of Fejér-Korovkin | Level of Wavelets Decomposition | Performance of Approximation Based on RMSE | | |
|---|---|---|---|---|
| | | Foreign Tourists ($\times 10^{-11}$) | Domestic Tourists ($\times 10^{-11}$) | Total Number of Tourists ($\times 10^{-11}$) |
| **4** | **2** | **1.2922** | **1.3352** | **2.2993** |
| | 3 | 1.6100 | 1.8337 | 2.7125 |
| | 4 | 2.0817 | 2.1608 | 2.8053 |
| | 5 | 2.0815 | 2.2828 | 5.5637 |
| | 6 | 1.9779 | 2.2536 | 5.5491 |
| | 8 | 1.9779 | 3.1851 | 5.6464 |
| Minimum of RMSE of 4th Order | | 1.2922 | 1.3352 | 2.2993 |
| 6 | 2 | **5.7646** | **8.4862** | **1.3.455** |
| | 3 | 8.6159 | 11.988 | 2.0.105 |
| | 4 | 10.246 | 14.956 | 2.4.786 |
| | 5 | 10.891 | 16.688 | 2.8.941 |
| | 6 | 11.623 | 20.161 | 3.0.596 |
| | 8 | 10.892 | 20.492 | 3.1.256 |
| Minimum of RMSE of 6th Order | | 5.7646 | 8.4862 | 1.3.455 |
| 8 | 2 | **9660200** | **13999000** | **22414000** |
| | 3 | 15374000 | 20998000 | 35351000 |
| | 4 | 16785000 | 22885000 | 38612000 |
| | 5 | 18325000 | 25975000 | 43176000 |
| | 6 | 22036000 | 28305000 | 49084000 |
| | 8 | 31038000 | 32175000 | 60803000 |
| Minimum of RMSE of 8th Order | | 9660200 | 13999000 | 22414000 |

The best approximator of the Fejér-Korovkin wavelet transformation is given by the fk4 approximator at level 2. The comparison graph between fk4 level 2 and the actual data is presented in Figure 4 (a). In the case of the number of foreign tourist visits, the best approximation performance was obtained RMSE value of **1.2922**$\times 10^{-11}$**,** and for the case of the number of domestic tourist visits, the best approximation performance was obtained RMSE value of **1.3352**$\times 10^{-11}$**,** and in the case of the total number of tourist visits the best approximation performance was obtained RMSE value of **2.2993**$\times 10^{-11}$**.**




**(a)**




**(b)**

**Figure 4. The Comparative Graph of the Reconstruction Results using (a) The 2nd Level of the 4th Order of Fejér-Korovkin Wavelets and (b) the 2nd Level of the 7th Order of Best-Localized Daubechies Wavelets with Actual Data for Each Classification of Tourist Data Visiting NTB Province for the Period January 2008 – December 2022.**

### 3.7 Best-Localized Daubechies Wavelet

The approximation of the data pattern of tourist visits to NTB Province based on the Best-localized Daubechies wavelet was simulated at various levels, namely levels 7, 9, and 10. Based on the RMSE indicator, it was produced that the estimation of the data pattern of the number of tourist visits to NTB using a wavelet transformation based on the Best-localized Daubechies function provides the RMSE value for the performance indicator of the ability to estimate as given in Table 8.

**Table 8. Performance of Approximation Tourism Data of NTB Province using the *n*-th Order Best-Localized Wavelets Transform Based on RMSE Indicator, *n* = 7, 9, and 10.**

| The Order of Best-localized Daubechies | Level of Wavelets Decomposition | Performance of Approximation Based on RMSE | | |
|---|---|---|---|---|
| | | Foreign Tourists ($\times 10^{-6}$) | Domestic Tourists ($\times 10^{-6}$) | Total Number of Tourists ($\times 10^{-6}$) |
| **bl7** | **2** | **1.0181** | **1.4262** | **2.3567** |
| | 3 | 1.5214 | 2.1352 | 3.5749 |
| | 4 | 1.7493 | 2.4855 | 4.1508 |
| | 5 | 1.9461 | 2.6756 | 4.5203 |
| | 6 | 2.3672 | 2.9358 | 5.1861 |
| | 8 | 3.1079 | 3.3709 | 6.2938 |
| Minimum of RMSE of 7th Order | | 1.0181 | 1.4262 | 2.3567 |
| bl9 | 2 | **9.7878** | **13.521** | **22.810** |
| | 3 | 1.3604 | 18.547 | 31.488 |
| | 4 | 1.6874 | 22.233 | 38.337 |
| | 5 | 2.0771 | 25.045 | 44.800 |
| | 6 | 2.5323 | 28.219 | 52.293 |
| | 8 | 3.2704 | 33.053 | 63.693 |
| Minimum of RMSE of 9th Order | | 9.7878 | 13.521 | 22.810 |
| bl10 | 2 | **28.704** | **39.190** | **66.407** |
| | 3 | 40.496 | 55.461 | 94.059 |
| | 4 | 48.658 | 65.337 | 111.78 |
| | 5 | 59.243 | 73.134 | 129.49 |
| | 6 | 72.379 | 81.822 | 150.71 |
| | 8 | 93.885 | 96.246 | 184.45 |
| Minimum of RMSE of 10th Order | | 28.704 | 39.190 | 66.407 |

The best approximator from the transformation of the Best-localized wavelet Daubechies is given by the bl7 approximator at level 2. The comparison graph between bl7 level 2 and the actual data is given in Figure 4 (b). In the case of the number of foreign tourist visits, the best approximation performance was obtained RMSE value of $\mathbf{1.0181}\times 10^{-6}$**,** and in the case of the number of domestic tourist visits, the best approximation performance was obtained RMSE value of $\mathbf{1.4262}\times 10^{-6}$**,** and in the case of the total number of tourist visits the best approximation performance was obtained RMSE value of $\mathbf{2.3567}\times 10^{-6}$.

### 3.8 Bi-orthogonal Splines Wavelet

The approximation of the data pattern of tourist visits to NTB Province based on Bi-orthogonal Splines wavelets was simulated at various levels, namely levels 1.3, 1.5, 2.6, 2.8, 3.5, and 3.7. Based on the RMSE indicator, it was produced that the estimation of the data pattern of the number of tourist visits to NTB using a wavelet transformation with the basis of the Bi-orthogonal Splines function provides the RMSE value for the performance indicator of the ability to approximate as given in Table 9.

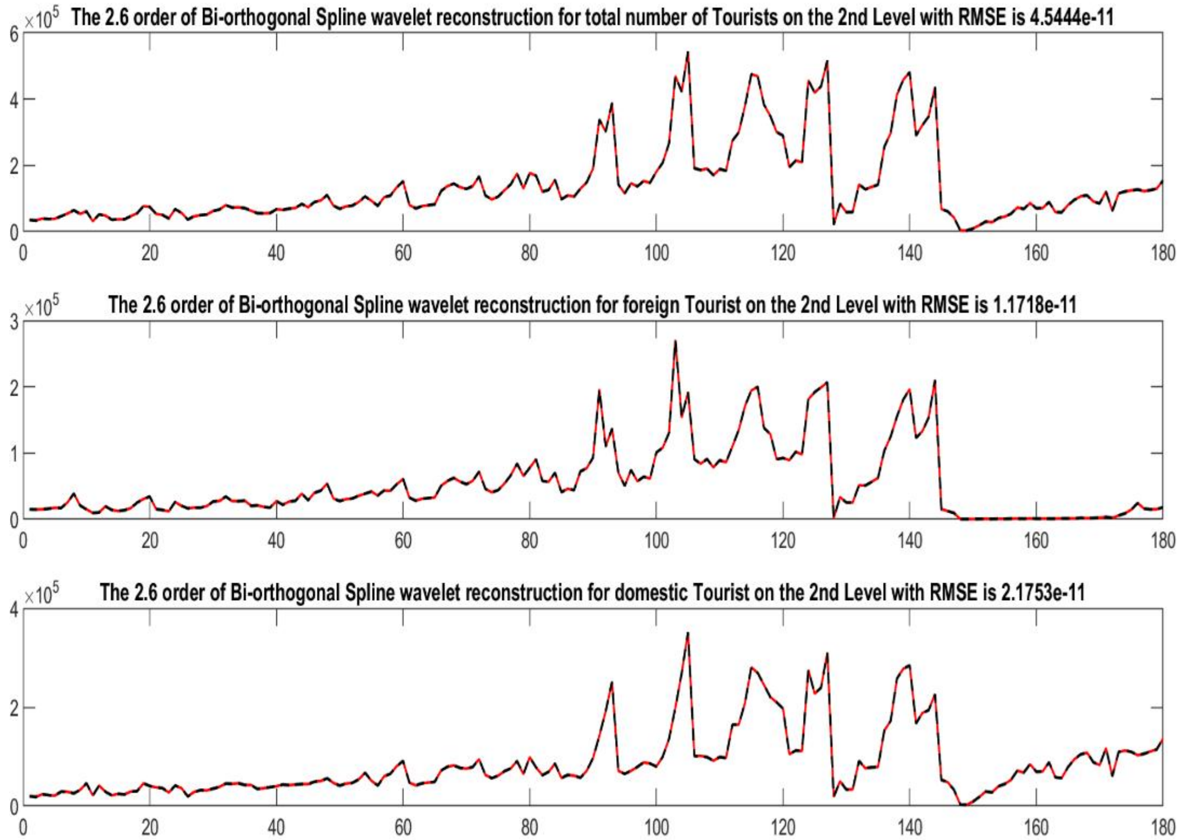



**Figure 5. The Comparative Graph of the Reconstruction Results Uses the 2 Levels of the 2.6 Order of Bi-Orthogonal Spline Wavelets with Actual Data for Each Classification of Tourist Data Visiting NTB Province for the Period January 2008 – December 2022.**

**Table 9. Performance of Approximation Tourism Data of NTB Province Using the *n*-th order Bi-Orthogonal Splines Wavelets Transform Based on RMSE Indicator, *n* = 1.3, 1.5, 2.6, 2.8, 3.5, and 3.7.**

| The Order of Biorthogonal Splines | Level of Wavelets Decomposition | Performance of Approximation Based on RMSE | | |
|---|---|---|---|---|
| | | Foreign Tourists ($\times 10^{-11}$) | Domestic Tourists ($\times 10^{-11}$) | Total Number of Tourists ($\times 10^{-11}$) |
| Bior1.3 | 2 | 2.3602 | 3.0373 | 5.6693 |
| | 3 | 3.8181 | 5.2574 | 8.0625 |
| | 4 | 4.6520 | 6.8419 | 9.2283 |
| | 5 | 6.4425 | 7.9409 | 10.058 |
| | 6 | 7.3708 | 9.0243 | 11.797 |
| | 8 | 7.9431 | 1.1.819 | 14.560 |
| Minimum of RMSE of 1.3 Order | | 2.3602 | 3.0373 | 5.6693 |
| Bior1.5 | 2 | 2.6343 | 3.3667 | 5.9345 |
| | 3 | 3.1299 | 5.3470 | 8.8243 |
| | 4 | 4.1858 | 6.2010 | 10.393 |
| | 5 | 4.8396 | 8.0188 | 12.892 |
| | 6 | 5.7596 | 8.6283 | 15.090 |
| | 8 | 5.7619 | 11.930 | 21.841 |
| Minimum of RMSE of 1.5 Order | | 2.6343 | 3.3667 | 5.9345 |
| **Bior2.6** | **2** | **1.1718** | **2.1753** | **4.5444** |
| | 3 | 1.8246 | 3.0728 | 6.2163 |
| | 4 | 2.4200 | 4.6017 | 6.7741 |
| | 5 | 3.0552 | 4.8100 | 9.8927 |
| | 6 | 4.6115 | 7.1463 | 10.029 |
| | 8 | 6.4895 | 7.2312 | 10.479 |
| Minimum of RMSE of 2.6 Order | | 1.1718 | 2.1753 | 4.5444 |
| Bior2.8 | 2 | 2.810 | 4.1118 | 5.9868 |
| | 3 | 3.6255 | 5.3822 | 7.4888 |
| | 4 | 3.6111 | 6.2285 | 11.512 |

| The Order of Biorthogonal Splines | Level of Wavelets Decomposition | Performance of Approximation Based on RMSE | | |
|---|---|---|---|---|
| | | Foreign Tourists ($\times 10^{-11}$) | Domestic Tourists ($\times 10^{-11}$) | Total Number of Tourists ($\times 10^{-11}$) |
| | 5 | 4.4253 | 6.8223 | 15.369 |
| | 6 | 4.8702 | 7.2052 | 15.293 |
| | 8 | 7.6363 | 8.7862 | 19.436 |
| Minimum of RMSE of 2.8 Order | | 2.8106 | 4.1118 | 5.9868 |
| Bior3.5 | 2 | 3.0836 | 3.4732 | 7.5221 |
| | 3 | 4.3823 | 4.9802 | 10.863 |
| | 4 | 4.7441 | 6.9298 | 13.134 |
| | 5 | 6.1896 | 7.0350 | 16.794 |
| | 6 | 6.3637 | 9.1029 | 19.975 |
| | 8 | 8.3413 | 9.7750 | 20.258 |
| Minimum of RMSE of 3.5 Order | | 3.0836 | 3.4732 | 7.5221 |
| Bior3.7 | 2 | 2.6631 | 3.9093 | 5.2863 |
| | 3 | 4.0788 | 5.6038 | 8.3767 |
| | 4 | 5.3329 | 6.5832 | 13.167 |
| | 5 | 6.0823 | 6.9573 | 15.252 |
| | 6 | 6.2996 | 7.5724 | 17.914 |
| | 8 | 9.6801 | 1.0.835 | 18.698 |
| Minimum of RMSE of 3.7 Order | | 2.6631 | 3.9093 | 5.2863 |

The best approximator resulting from the transformation of Bi-orthogonal wavelet Splines was given by **the bior2.6** approximator at level 2. The comparison graph between bior2.6 level 2 and the actual data is given in **Figure 5**. In the case of the number of foreign tourist visits, the best approximation performance was obtained RMSE value of **1.1718**$\times 10^{-11}$**,** and in the case of the number of domestic tourist visits, the best approximation performance was obtained RMSE value of **2.1753**$\times 10^{-11}$**,** and in the case of the total number of tourist visits the best approximation performance was obtained RMSE value of **4.5444**$\times 10^{-11}$.

### 3.9 Discussion

Based on the simulation results of several wavelet functions as the basis for Subchapter 3.2 to 3.8, it produces the transformation's type, order, and decomposition level that gives the best approximation results based on the RMSE indicator (**Table 10**). These results confirm that among several types of wavelets that are simulated to estimate the number of foreign tourist visits to NTB Province, wavelets with Bi-orthogonal Splines order 2.6 (**bior2.6**) at the 2nd decomposition level are the best approximation tools with an RMSE value of $1.1718\times 10^{-11}$ . Meanwhile, for the estimation of the number of domestic tourist visits and the total number, the best estimation was given by the Fejér-Korovkin wave of order 4 (**fk4**) and the best-localized Daubechies wave of order 7 (**bl7**) at the 2nd level with an RMSE value of $1.3352 \times 10^{-11}$for domestic tourists and $2.2993 \times 10^{-11}$for the total number of tourists visiting NTB Province.

**Table 10. Summary of the Wavelet Types with the Order and Level of Wavelet Decomposition that have the best Performance Based on RMSE Value for Approximating NTB Province Tourism Data Using Wavelet Transform.**

| Types of Wavelets | Notation | Wavelet Decomposition | Performance of Approximation Based on RMSE | | |
|---|---|---|---|---|---|
| | | | Foreign Tourists | Domestic Tourists | Total Tourists Number |
| Haar | Haar | 2 | $2.3813 \times 10^{-11}$ | $3.4908 \times 10^{-11}$ | $5.2687 \times 10^{-11}$ |
| Symlets | sym5 | 2 | $1.0298 \times 10^{-8}$ | $1.4778 \times 10^{-8}$ | $2.3690 \times 10^{-8}$ |
| Coiflets | coif3 | 2 | $4.5223 \times 10^{-8}$ | $5.8559 \times 10^{-8}$ | $9.9102 \times 10^{-8}$ |
| Daubechies | db2 | 2 | $3.6420 \times 10^{-8}$ | $5.0602 \times 10^{-8}$ | $8.3602 \times 10^{-8}$ |
| **Fejér-Korovkin** | **fk4** | **2** | $1.2922 \times 10^{-11}$ | $\mathbf{1.3352} \times 10^{-11}$ | $\mathbf{2.2993} \times 10^{-11}$ |
| **Best-Localized Daubechies** | **bl7** | **2** | $1.2922 \times 10^{-11}$ | $\mathbf{1.3352} \times 10^{-11}$ | $\mathbf{2.2993} \times 10^{-11}$ |
| **Bi-orthogonal Spline** | **bior2.6** | **2** | $\mathbf{1.1718} \times 10^{-11}$ | $2.1753 \times 10^{-11}$ | $4.5444 \times 10^{-11}$ |

Based on the data pattern of the estimation results in **Figure 2** to **Figure 6** and supported by a fairly small RMSE indicator value, it shows that all types of wavelets in various orders and levels of wavelet decomposition that are simulated provide results that are representative enough to be used as a tool in estimating the number of tourist visits to NTB Province. This result is in line with the results of Maharaj **[29]** which states that wavelet transform can be used to identify and model time series data patterns.

Although the wavelet transform is a powerful tool for time series analysis, particularly in modeling tourist visits, it has several inherent limitations: First, limited effectiveness for multi-scale seasonality: while wavelet transforms excel at analyzing fixed-frequency patterns, they struggle to capture multi-scale seasonal variations (e.g., daily, weekly, and annual fluctuations in tourist arrivals). Second, sensitivity to noise and complex trends: tourist visit data often contain noise (e.g., random daily fluctuations) and outliers (e.g., sudden spikes due to festivals or events). Additionally, such data typically exhibit seasonal trends (e.g., holiday peaks). Wavelet transforms are suboptimal for handling these complexities without significant preprocessing. Lastly, Computational overhead for non-stationary data: non-stationary data requires advanced adaptations (e.g., wavelet packet transforms), which increase computational complexity and reduce scalability.

To overcome this problem, a hybrid approach—combining wavelet transforms with neural networks, fuzzy inference systems, or statistical methods—can mitigate these limitations and enhance predictive accuracy.

## 4. CONCLUSIONS

Wavelet transformation is one of the "good" tools for estimating time series data, including data on tourist visits to West Nusa Tenggara Province. The application of several types of wavelets as an approximation base, namely the Haar, Symlets, Coiflets, Daubechies, Fejér-Korovkin, best-localized Daubechies, and Bi-orthogonal Splines on tourist visit data both simultaneously and partially, for the case of domestic and foreign tourists gave quite significant results both based on the RMSE indicator and seen from the output patterns produced. The simulation results show that the best approximation model for the case of the total number of tourists is given by the wavelet transformation with the base of Fejér-Korovkin type wavelet order 4 (fk4) level 2 and the best-localized Daubechies order 7 (bl7) type wavelet level 2 with an RMSE value of $2.2993 \times 10^{-11}$. Partially, the best approximation model for foreign tourist cases is given by wavelet transformation with a level 2 Bi-orthogonal Spline wavelet (bior2.6) wavelet base with an RMSE value of $1.1718 \times 10^{-11}$, and the best approximation model for domestic tourist cases is given by wavelet transformation with a Fejér-Korovkin order 4 (fk4) wavelet type wavelet base level 2 and best-localized Daubechies order 7 (bl7) level 2 wavelet with an RMSE value of $1.3352 \times 10^{-11}$.

In its application, the wavelet transform is very powerful for time series analysis, especially tourist visits, but the wavelet transform has limitations in noise handling, non-stationarity, and long-term prediction. Integration with other models, such as AI or statistical methods, is an alternative step to obtain optimal results.

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