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A Comparison of the Admiralty, Least Squares, and Support Vector Regression (SVR) Methods for Tidal Data Processing

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Abstract

The accuracy of tidal prediction depends on the analytical method employed, making method selection a critical aspect of tidal data processing. This study compares the performance of three tidal analysis methods: Admiralty, Least Squares, and Support Vector Regression (SVR). The methods were applied to tidal observations from three stations with different tidal range characteristics: Pemenang (West Nusa Tenggara), Sorong (West Papua), and Tuapejat (West Sumatra). Data were obtained from the Indonesian Geospatial Reference System (SRGI) managed by the Geospatial Information Agency (BIG). The Admiralty method used 29 days of observations (January 2023), whereas the Least Squares and SVR methods utilized three years of data (2021–2023). Model performance was evaluated using Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). Results show that SVR achieved the highest accuracy at all stations, with RMSE values below 0.005 m and MAPE below 0.33%. Least Squares produced moderate accuracy (RMSE: 0.0693–0.1390 m; MAPE: 3.65–11.97%), while Admiralty yielded the largest errors (RMSE up to 0.683 m; MAPE up to 52.7%). These findings highlight the importance of considering data availability and local tidal characteristics when selecting a tidal analysis method.

Keywords: tides; tidal data processing; admiralty method; least squares method; support vector regression (SVR)

1. Introduction

Accurate tidal information is essential for a wide range of marine activities, particularly for ensuring navigational safety, supporting hydrographic surveys, and facilitating coastal zone planning and management. Errors in tidal prediction can lead to inaccuracies in water depth determination and increase operational risks at sea. Therefore,

reliable tidal data processing is a critical component of marine surveying activities.

Tidal analysis is commonly performed using harmonic approaches. Various methods have been developed to derive harmonic constituents and generate tidal predictions with different levels of accuracy. The Admiralty method is a classical tabular technique that derives nine primary harmonic constituents from 15–29 days of observations, making it practical for preliminary analyses but limited in complex coastal environments (Arisandi & Ashury, 2019). The Least Squares method utilizes long-term observations to estimate amplitudes and phases by minimizing the squared differences between observed and predicted values, enabling the extraction of a more comprehensive set of harmonic constituents (Supriyono et al., 2022). In contrast, Support Vector Regression (SVR), a machine-learning-based approach, can model nonlinear relationships in tidal data through kernel functions, making it more adaptable to variations in sea-level dynamics (Utami et al., 2021).

The different theoretical foundations and mathematical approaches of these methods may lead to variations in prediction accuracy under different tidal conditions. Although previous studies have evaluated the Admiralty, Least Squares, and SVR methods separately, comparative studies that simultaneously assess all three methods across locations with different tidal range characteristics in Indonesia remain limited (Ichsari et al., 2020). This gap is significant because tidal range variability may influence the ability of each method to represent local tidal dynamics. The Admiralty method, which relies on short observation periods, may provide less accurate predictions in areas with large sea-level variations, whereas the Least Squares and SVR methods, which utilize long-term datasets, are expected to yield higher accuracy.

To address this research gap, this study compares the performance of the Admiralty, Least Squares, and SVR methods using tidal data obtained from the Indonesian Geospatial Reference System (SRGI) managed by the Geospatial Information Agency (BIG). The analysis was conducted at three stations representing different tidal range characteristics: Pemenang (West Nusa Tenggara), Sorong (West Papua), and Tuapejat (West Sumatra). Method performance was evaluated using Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) to identify the most accurate method under varying tidal conditions.

2. Materials and Methods

2.1 Study Area

The study area comprises three tidal observation stations located in the following regions:

Table 1. Location of Tidal Observation Stations.

Tidal Stasions	Latitude	Longitude	Province
Pemenang (PMNG)	8°23’32.604” LS	116°5’56.616” BT	Nusa Tenggara Barat
Sorong (SRNG)	0°52’37.740” LS	131°14’37.140” BT	Papua Barat
Tuapejat (TPJT)	2°1’47.892” LS	99°35’36.312” BT	Sumatera Barat

The study sites were selected based on tidal range characteristics in Indonesian waters. Tides are commonly classified as microtidal (< 2 m), mesotidal (2–4 m), and macrotidal (> 4 m). Since Indonesian waters are predominantly microtidal to mesotidal, this study focused on mesotidal environments. Based on tidal data from the Indonesian Geospatial Reference System (SRGI) managed by the Geospatial Information Agency (BIG), Sorong (West Papua) and Pemenang (West Nusa Tenggara) stations were selected. Both stations are classified as mesotidal but exhibit

different tidal ranges, approximately 2.4 m and 2.9 m, respectively, representing variability within the mesotidal categ**ory.**

2.2 Tidal Data

Tidal data used in this study were obtained from the Geospatial Information Agency (BIG). The data were provided in text (.txt) format with an hourly observation interval, containing date, time, and sea-level height records in centimeters (cm). Historical data from 2021–2023 were utilized according to the requirements of each analysis method.

2.3 Admiralty Processing Method

The Admiralty method is a classical harmonic tidal processing method that estimates the amplitude and phase of nine principal tidal constituents (M2, S2, N2, K1, O1, M4, MS4, P1, and K2) from short-term observations (15–29 days) (Pawlowicz et al., 2002). The analysis is carried out with the help of a special table to determine amplitude and phase. The calculations involve astronomical variables such as s, h, p, and N, which are elements of the lunar and solar orbits as described by Schureman (1988). In this research practice, data processing is performed using seven calculation schemes.

The main advantage of the Admiralty method is its simplicity. Using relatively short observation records, it can provide estimates of tidal characteristics and mean sea level without requiring complex computational tools, making it suitable for applications with limited resources (Pasaribu et al., 2022). However, because it relies on only nine principal harmonic constituents, its accuracy is generally lower for long-term analyses and in areas with complex geomorphological and tidal conditions, potentially limiting its ability to fully represent actual sea-level variations (Supriyono et al., 2022). Nevertheless, the Admiralty method remains relevant in modern oceanographic studies and is frequently used as a baseline for comparison with more advanced methods.

2.4 Least Squares Processing Method

The Least Squares (LS) method is a mathematical technique that estimates model parameters by minimizing the sum of squared differences between observed and predicted values. In tidal studies, it is employed to determine the amplitudes and phases of harmonic constituents from long-term observational data, resulting in more comprehensive and accurate analyses than those obtained using the Admiralty method (Supriyono et al., 2022). The following Equation (1) represents the harmonic that is solved using least squares to obtain the amplitude and phase of the harmonic constants.

$$\boldsymbol{h(t_i) = Co + \sum_{j=1}^{m} a_j f_j \cos\cos\left(\omega_j t_i + v_j - g_j\right)} \quad (1)$$

where C_0 is the Mean Sea Level (MSL) relative to the adopted datum; α is the amplitude constant; ω is the angular frequency; t is time; g is the initial phase of the tidal constituent (at t = 0); h(t) is the sea level at time t; f is the nodal correction factor for amplitude; v is the equilibrium tidal correction factor for phase; and m is the number of tidal constituents.

Least Squares computations were performed using T_Tide, a MATLAB-based harmonic analysis package designed for tidal data analysis. T_Tide estimates the amplitudes and phases of tidal constituents, supports tidal prediction and uncertainty estimation, and can process long-term datasets, making it suitable for both scientific and practical applications (Akbar et al., 2024).

2.5 Support Vector Regression (SVR) Processing Method

Support Vector Regression (SVR) is a machine learning–based regression method derived from Support Vector Machines (SVM). SVR constructs an optimal regression function by minimizing prediction errors while maximizing the margin. Through kernel functions, it can model complex nonlinear relationships by mapping data into a higher-dimensional feature space (Utami et al., 2021). In this study, SVR was implemented using Python and the scikit-learn library. A radial basis function (RBF) kernel was employed to capture nonlinear relationships between the predictor variables and observed tidal water levels. The model performance was controlled by three main hyperparameters: the regularization parameter (C), the epsilon-insensitive loss parameter (ε), and the kernel coefficient (γ).

The SVR model adopted a harmonic-feature-based approach, in which sine and cosine functions of the selected tidal constituent frequencies were used as predictor variables. These harmonic features provide astronomical frequency information to the regression model, while SVR estimates the nonlinear relationship between the harmonic predictors and observed water levels. Thus, the proposed approach combines harmonic tidal information with machine learning rather than relying exclusively on a purely data-driven framework

For model development and evaluation, the dataset was divided into training and testing subsets using a 70:30 ratio, respectively. The first 70% of the observations were used to train the SVR model, while the remaining 30% were reserved for independent testing to evaluate its predictive performance.

2.6 Performance Evaluation Method

Model performance was evaluated using Root Mean Square Error (RMSE), which measures the average magnitude of prediction errors by calculating the square root of the mean squared differences between predicted and observed values. Lower RMSE values indicate higher prediction accuracy and better model performance. The RMSE equation is presented in Equation (2):

$$\text{RMSE} = \sqrt{\sum \frac{(X-\underline{X})^2}{n}} \quad \text{.....(2)}$$

In addition to RMSE, model performance was evaluated using Mean Absolute Percentage Error (MAPE), which measures the average percentage difference between predicted and observed values. Lower MAPE values indicate higher prediction accuracy. The MAPE equation is presented in Equation (3) (Alviani Krisma et al., 2019):

$$\text{MAPE} = \left(\frac{100\ \%}{n}\right) \sum_{t=1}^{n} \frac{|Xt - Ft|}{Xt} \quad \text{.....(3)}$$

where Xt is observed value at time period t; Ft is predicted value at time period t, number of observations (n).

MAPE measures the average percentage error between predicted and observed values, with lower values indicating higher accuracy. According to Lewis (1982, cited in Nurani et al., 2023), MAPE values below 10% indicate excellent performance, 10–20% good, 20–50% acceptable, and above 50% poor performance. Previous studies have demonstrated the effectiveness of MAPE in tidal prediction, with SVR achieving MAPE values as low as 0.55% (Utami et al., 2021).

In this study, RMSE and MAPE were used jointly to provide a comprehensive evaluation of model performance. RMSE quantifies absolute prediction errors and is sensitive to outliers, whereas MAPE expresses errors as percentages, enabling comparisons across stations with different tidal ranges (Nurani et al., 2023). Therefore, the optimal method is defined as the one that consistently produces the lowest RMSE and MAPE values across all study locations.

3. Results

3.1 Results of Admiralty Method processing

The Admiralty method produced nine principal harmonic constituents at each study site. The amplitudes of these constituents are presented in Table 2.

Table 2. Amplitudes of Principal Harmonic Constituents at Each Study Site Using the Admiralty Method.

Locations	M_2 (cm)	S_2 (cm)	N_2 (cm)	K_1 (cm)	O_1 (cm)	M_4 (cm)	MS_4 (cm)	K_2 (cm)	P_1 (cm)
Pemenang	26.04	5.52	19.14	25.12	22.85	1.37	0.49	1.49	8.29
Sorong	45.60	7.71	57.45	12.89	12.76	0.32	0.22	2.08	4.25
Tuapejat	33.93	5.16	45.34	9.35	7.98	1.23	0.26	1.39	3.09

As shown in Table 2, the Admiralty results indicate that M2 is the dominant tidal constituent at Pemenang (26.04 cm), whereas N2 exhibits higher amplitudes than M2 at Sorong (57.45 cm versus 45.60 cm) and Tuapejat (45.34 cm versus 33.93 cm). Although such variations may reflect local hydrodynamic responses, the unusually high N2 amplitudes warrant further investigation. The close frequencies of M2 and N2 require approximately 27.55 days of observations to be resolved according to the Rayleigh criterion (NOAA, 2000). Therefore, despite the 29-day observation period theoretically meeting this criterion, uncertainties in constituent estimation may remain. Furthermore, the Least Squares and Support Vector Regression (SVR) results consistently identify M2 as the dominant constituent, suggesting sensitivity to the processing approach. Consequently, the N2 dominance obtained from the Admiralty method should be interpreted cautiously and further examined by verifying the harmonic constants, astronomical correction factors, and estimation procedures (Pawlowicz et al., 2002; NOAA, 2000).

Table 3. Tidal Elevations at Each Study Site Derived from the Admiralty Method

Lokasi	MSL (m)	HHWL (m)	LLWL (m)	Tidal Range (m)
Pemenang	1.60	2.65	0.39	2.26
Sorong	1.59	2.51	0.51	2.00
Tuapejat	1.00	1.84	0.46	1.38

As shown in Table 3, the largest tidal range was observed at Pemenang (2.26 m), followed by Sorong (2.00 m) and Tuapejat (1.38 m). Although Sorong exhibited the highest M2 amplitude, the combined effects of harmonic constituents resulted in the greatest tidal range at Pemenang. Mean Sea Level (MSL) was highest at Pemenang (1.60 m) and lowest at Tuapejat (1.00 m), reflecting differences in vertical reference levels among stations. Comparisons between observed and Admiralty-predicted tides are presented in Figures 1 - 3.

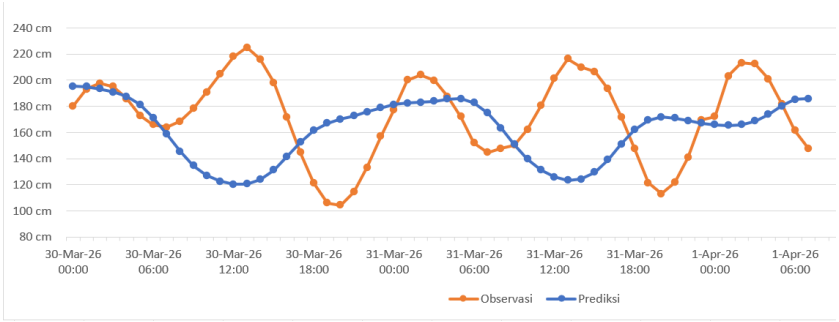


Figure 1. Admiralty Method Tidal Curve at Pemenang.

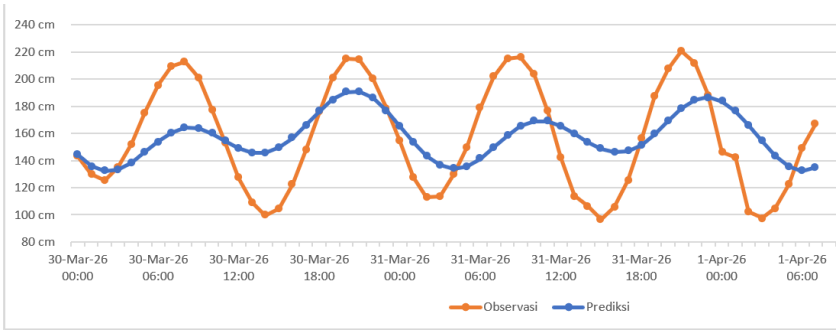


Figure 2. Admiralty Method Tidal Curve at Sorong Station.

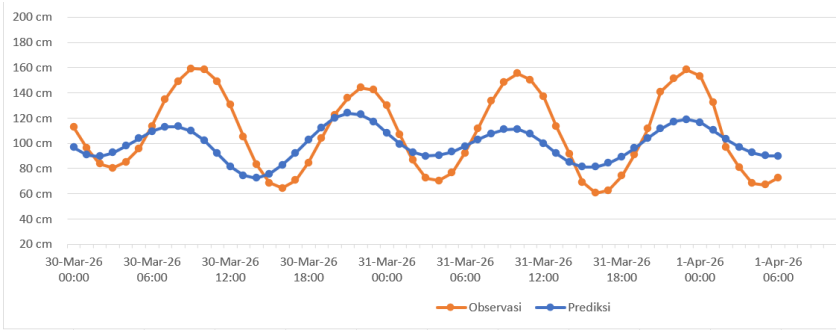


Figure 3. Admiralty Method Tidal Curve at Tuapejat Station.

Figures 1–3 show that the Admiralty method generally reproduced the main tidal patterns at all stations. At Pemenang, the predicted curve followed the observed periodic trend but tended to overestimate peak tides. At Sorong, semidiurnal fluctuations were well represented, although noticeable deviations occurred during high and low tides. At Tuapejat, phase mismatches were observed in several cycles, with predicted and observed peaks not always occurring simultaneously. Overall, the Admiralty method captured the dominant tidal variability, but discrepancies in amplitude and phase during extreme conditions highlight the limitations of short-term harmonic analysis.

3.2 Results of Least Squares Method processing

The Least Squares method was applied to three years of tidal data (2021–2023) from all study sites. The use of long-term observations enabled the identification of substantially more harmonic constituents than the Admiralty method. Approximately 60 harmonic constituents were resolved at each station;

however, many had negligible amplitudes and contributed little to sea-level variability. Therefore, only the dominant constituents with significant amplitudes are presented in this section. The dominant harmonic constituents derived from the Least Squares analysis are shown in Table 4.

Table 4. Amplitudes of Principal Harmonic Constituents at Each Study Site Using the Least Squares Method.

Lokasi	M_2 (cm)	S_2 (cm)	N_2 (cm)	K_1 (cm)	O_1 (cm)	M_4 (cm)	MS_4 (cm)	K_2 (cm)	P_1 (cm)
Pemenang	26.4	14.03	5.06	36.29	22.52	0.29	0.36	4.27	11.39
Sorong	44.42	18.92	8.39	18.82	12.08	0.28	0.05	4.97	6.07
Tuapejat	33.83	13.54	13.54	13.37	7.76	1.58	0.21	3.97	3.97

As shown in Table 4, M_2 was the dominant constituent at all study sites, with the highest amplitude recorded at Sorong (44.42 cm), followed by Tuapejat (33.83 cm) and Pemenang (26.40 cm), indicating strong semidiurnal lunar forcing. S_2 also contributed significantly, particularly at Sorong (18.92 cm). In contrast, Pemenang exhibited a K_1 amplitude (36.29 cm) greater than M_2, indicating a stronger diurnal influence. At Sorong and Tuapejat, semidiurnal constituents remained dominant. Shallow-water constituents such as M_4 and MS_4 showed relatively small amplitudes at all stations, suggesting limited nonlinear shallow-water effects. Key tidal elevations derived from the Least Squares method are presented in Table 5.

Table 5. Tidal Elevations at Each Study Site Derived from the Least Squares Method

Lokasi	MSL (m)	HHWL (m)	LLWL (m)	Tidal Range (m)
Pemenang	1.57	2.62	0.41	2.20
Sorong	1.55	2.,45	0.44	2.01
Tuapejat	1.08	1.97	0.45	1.51

As shown in Table 5, Pemenang exhibited the largest tidal range (2.20 m), followed by Sorong (2.01 m) and Tuapejat (1.51 m). Although Sorong had the highest M_2 amplitude, the stronger diurnal contribution at Pemenang produced a greater tidal range. Mean Sea Level (MSL) was highest at Pemenang (1.57 m) and lowest at Tuapejat (1.08 m). The HHWL and LLWL estimates were consistent with the observed tidal characteristics, indicating that the long-term harmonic analysis reliably represented maximum and minimum sea-level variations. Comparisons between observed and predicted tides are presented in Figures 4–6.

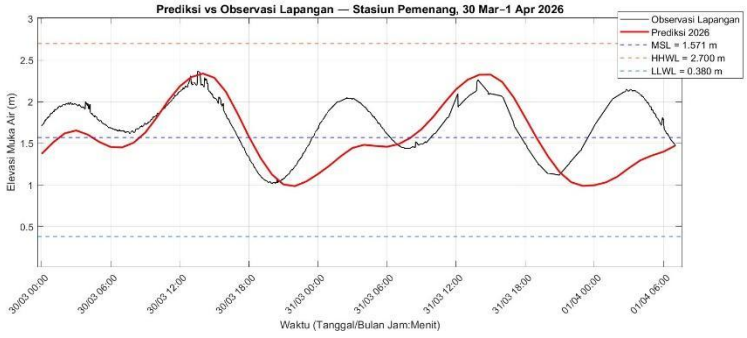


Figure 4. Least Squares Method Tidal Curve at Pemenang Station.

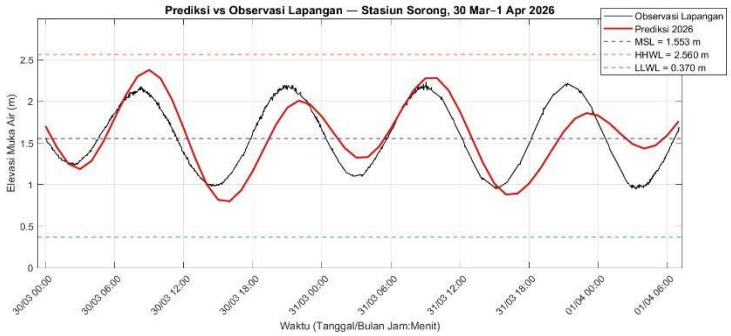


Figure 5. Least Squares Method Tidal Curve at Sorong Station.

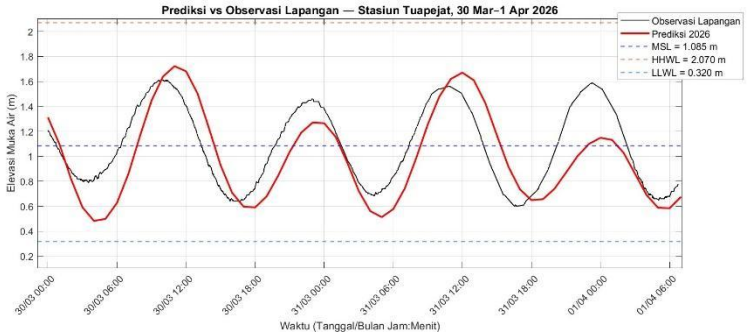


Figure 6. Least Squares Method Tidal Curve at Tuapejat Station.

Figures 4–6 show that the Least Squares predictions generally matched the observed tides more closely than the Admiralty method. At Pemenang, the predicted curve followed the observed pattern well, although slight differences remained at some peak tides. At Sorong, excellent agreement was observed, with the model accurately reproducing the dominant semidiurnal pattern. At Tuapejat, the predicted and observed curves were also closely aligned, with only minor amplitude discrepancies. Overall, the Least Squares method provided substantially better agreement across all stations, demonstrating the benefit of long-term data for more stable and accurate tidal predictions.

3.3 Results of Support Vector Regression Method processing

Support Vector Regression (SVR) was applied using tidal constituent frequencies based on standard astronomical frequencies (Doodson numbers). Sine and cosine components of each frequency were used as regression variables, and the resulting coefficients were converted into amplitudes and phases of harmonic constants, while preserving the physical tidal structure. The dominant harmonic constants obtained from the SVR are presented in Table 6.

Table 6. Amplitudes of Principal Harmonic Constituents at Each Study Site Using the SVR Method.

Lokasi	M_2 (cm)	S_2 (cm)	N_2 (cm)	K_1 (cm)	O_1 (cm)	M_4 (cm)	MS_4 (cm)	K_2 (cm)	P_1 (cm)
Pemenang	25.76	14.12	5.01	39.64	26.02	0.31	0.35	5.29	11.34
Sorong	43.51	19.05	8.26	20.41	13.89	0.24	0.03	6.07	6.16
Tuapejat	33.05	13.59	7.56	14.52	8.98	1.48	0.21	4.68	4.02

Based on Table 6, M_2 is the dominant tidal constituent at all stations, with the highest amplitude at Sorong (43.51 cm), followed by Tuapejat (33.05 cm) and Pemenang (25.76 cm), indicating a strong semidiurnal lunar tidal influence.

S_2 also contributes significantly, especially at Sorong (19.05 cm), reinforcing semidiurnal dominance. At Pemenang, K_1 (39.64 cm) and O_1 (26.02 cm) are relatively large, indicating a stronger diurnal influence and a mixed tide tending toward diurnal.

Shallow-water constituents (M_4, MS_4) are small, showing weak nonlinear effects. Overall, SVR results are consistent with the Least Squares method, confirming that the main tidal harmonic structure is well preserved. Table 7 presents key water level values from SVR.

Table 7. Tidal Elevations at Each Study Site Derived from the SVR Method

Lokasi	MSL (m)	HHWL (m)	LLWL (m)	Tidal Range (m)
Pemenang	1.56	2.70	0.35	2.35
Sorong	1.55	2.56	0.37	2.19
Tuapejat	1.08	2.07	0.32	1.75

Tidal range is highest at Pemenang (2.35 m), followed by Sorong (2.19 m) and Tuapejat (1.75 m), consistent with stronger diurnal influence at Pemenang that produces a larger range. Mean Sea Level (MSL) is highest at Pemenang (1.56 m) and lowest at Tuapejat (1.08 m). HHWL and LLWL values remain within reasonable limits without extreme deviations, indicating stable representation of sea level extremes by the SVR model. Overall, SVR results are consistent and reliable, as shown by the comparison between observed and predicted data in Figures 7–9.

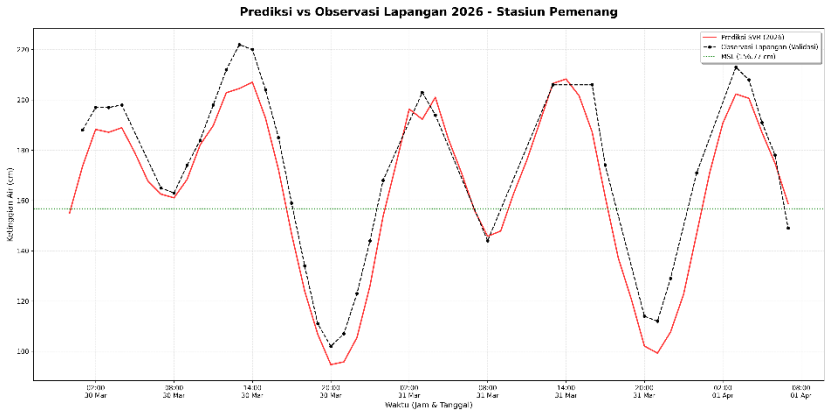


Figure 7. SVR Method Tidal Curve at Pemenang Station.

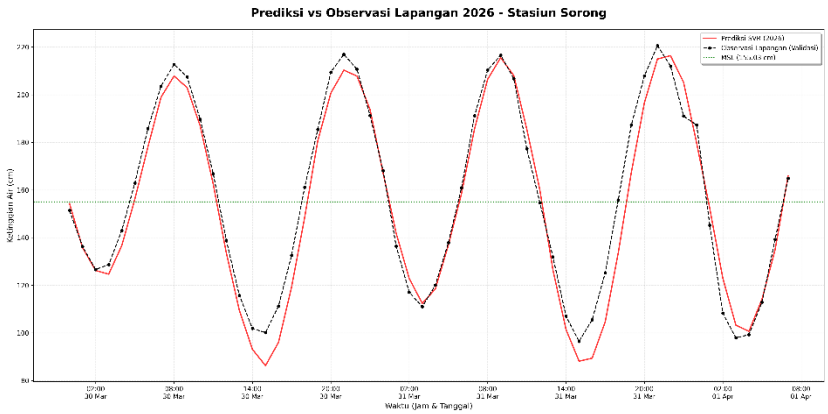


Figure 8. SVR Method Tidal Curve at Sorong Station.

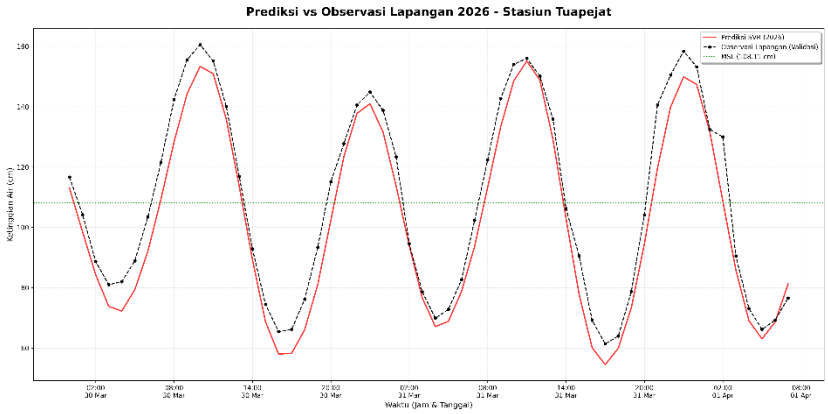


Figure 9. SVR Method Tidal Curve at Tuapejat Station.

At Pemenang Station (Fig. 7), the SVR prediction closely matches observations throughout the period, accurately capturing high and low tides using the RBF kernel, including non-linear tidal behavior. At Sorong (Fig. 8), the agreement between prediction and observation is very high, with well-reproduced semidiurnal patterns and nearly identical peaks and troughs. At Tuapejat (Fig. 9), SVR also follows observed fluctuations well, although with slightly smaller amplitudes and minor non-systematic deviations at some peaks. Overall, SVR provides the best visual fit across all stations, demonstrating the effectiveness of kernel-based machine learning in capturing complex non-linear tidal dynamics.

3.4 Comparative Performance Analysis of the Three Methods

The performance of the Admiralty, Least Squares, and Support Vector Regression (SVR) methods was evaluated using Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). RMSE measures the average prediction error in meters, while MAPE represents the relative error percentage compared to observed data. A comparison of RMSE and MAPE values for the three study locations is presented in Table 8.

Table 8. RMSE and MAPE values for each method

Lokasi	Metode	RMSE (m)	MAPE(%)
Pemenang	Admiralty	0.6833	41.5
	Least Square	0.0783	4.46
	SVR	0.0041	0.28
Sorong	Admiralty	0.4827	27.50
	Least Square	0.0693	3.65
	SVR	0.0038	0.26
Tuapejat	Admiralty	0.5865	52.70
	Least Square	0.1390	11.97
	SVR	0.0032	0.32

SVR shows the smallest RMSE across all locations, with Pemenang (0.004153 m), Sorong, and Tuapejat all below 0.005 m. This indicates a very high ability to represent sea level fluctuations. Least Squares performs reasonably well (RMSE < 0.14 m) but with higher deviation, while Admiralty shows the largest errors, especially at Tuapejat (0.5865 m), due to its reliance on short-term data.

MAPE results show a similar pattern. SVR produces the lowest error (<0.35%), indicating very high accuracy. Least Squares shows moderate errors (3.65%–11.97%), while Admiralty has the highest error, reaching 52.7% at Tuapejat, indicating poor representation of tidal variability from short-term observations.

Overall, SVR performs best at all locations based on both RMSE and MAPE, followed by Least Squares with stable performance. Admiralty shows the weakest performance, suggesting limited effectiveness for long-term tidal representation using short-duration data.

3.5 Comparison of the Characteristics of Results from the Three Methods

The comparison was conducted to provide a comprehensive overview of the characteristics, representational capability, and accuracy of each method in tidal data analysis.

Overall, all three methods show similar harmonic amplitude patterns, with M_2 as the dominant constituent across all stations, indicating that semidiurnal lunar tides are the primary driver of sea level variability. However, notable differences occur in certain components. At Sorong, Admiralty produces a significantly higher N_2 amplitude than Least Squares and SVR, likely due to its sensitivity to short-term data, whereas Least Squares and SVR provide more stable long-term estimates. At Pemenang, an interesting condition is observed where the diurnal K_1 component (Least Squares and SVR) exceeds M_2, indicating a stronger diurnal influence. This suggests mixed tides tending toward diurnal dominance, influenced by local factors such as coastline geometry, bathymetry, and sea-floor topography, as well as better identification of long-period signals from long-term datasets.

The methods also differ in harmonic representation. Admiralty uses only nine fixed constituents, limiting local adaptability. Least Squares (e.g., via T_Tide) can extract dozens of constituents, including shallow-water components, providing more detailed tidal representation. SVR, on the other hand, does not explicitly separate harmonic constituents but models tidal signals using nonlinear kernel-based learning, allowing it to capture complex patterns more flexibly.

Data length also affects performance. Admiralty (29-day data) is prone to short-term bias, while Least Squares and SVR (3-year data) better capture full astronomical cycles and reduce noise, resulting in more stable outputs.

In terms of advantages, Admiralty is simple and computationally efficient but less accurate. Least Squares offers good physical interpretability but limited nonlinear capability. SVR provides the highest accuracy but has lower interpretability and requires parameter tuning.

Accuracy evaluation shows SVR consistently achieves the lowest RMSE and MAPE, followed by Least Squares and Admiralty. Similarly, SVR produces the highest tidal range estimates, followed by Least Squares and Admiralty. Differences arise from SVR's ability to capture nonlinear tidal extremes using the RBF kernel, whereas Least Squares assumes linear harmonic behavior and Admiralty relies on short-term data. Pemenang consistently shows the largest tidal range due to combined contributions of multiple constituents, particularly strong diurnal components (K_1, O_1), not only M_2 dominance.

In conclusion, SVR is most suitable for high-accuracy operational prediction, Least Squares is preferred for physically interpretable harmonic analysis, and Admiralty is best suited for

preliminary assessment with limited data. No single method is universally superior across all aspects; selection should depend on data availability and analytical objectives.

4. Conclusions

Based on tidal analysis using Admiralty, Least Squares, and Support Vector Regression (SVR) at Pemenang, Sorong, and Tuapejat Stations, each method shows different characteristics and accuracy levels.

Admiralty produces only nine harmonic constituents, resulting in a simple representation that is less capable of capturing complex tidal variability. Least Squares provides more detailed and physically interpretable harmonic constituents but still has limitations in modeling nonlinear patterns. SVR does not explicitly generate harmonic constants but can flexibly model nonlinear tidal relationships using a machine learning approach.

Evaluation using RMSE and MAPE shows that SVR consistently yields the lowest errors across all stations (RMSE < 0.005 m; MAPE < 0.33%). Least Squares ranks second (RMSE 0.0693–0.1390 m; MAPE 3.65%–11.97%), while Admiralty shows the highest errors (RMSE up to 0.683 m; MAPE up to 52.7%). These results indicate that SVR provides the highest predictive accuracy under varying tidal conditions.

Therefore, the hypothesis that SVR outperforms Admiralty and Least Squares in tidal prediction is accepted. However, each method remains useful depending on the objective: Admiralty for preliminary analysis, Least Squares for physically interpretable harmonic analysis, and SVR for high-accuracy prediction.

5. Declaration of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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