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Analysis of Wind Characteristics in Tuban Regency Waters, East Java: Implications for Small-Scale Fishery Operations

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Abstract

Wind is a critical meteorological parameter influencing sea conditions, fishing vessel safety, and the effectiveness of capture fisheries in coastal waters. This study analyzes wind characteristics in the waters of Tuban Regency, East Java, Indonesia, based on observational data from the BMKG Maritime Meteorological Station Perak Surabaya. Wind speed and direction data from October to December 2025 were analyzed using descriptive statistics and windrose diagrams to identify dominant wind patterns and their implications for small-scale fisheries. The results show that wind speeds generally ranged from 2 to 6 knots, with occasional increases to 10-12 knots, particularly from late November to early December. The dominant wind directions originated from the west (W), southwest (SW), and south (S) sectors, consistent with the seasonal monsoon transition. The average wind speed of 5 -6 knots is categorized as light to moderate, which is generally safe for small-scale fishing operations. However, speed fluctuations exceeding 10 knots require adaptive fishing strategies. This study provides baseline information for improving weather-based fisheries management and safety planning in the southern Java Sea region .

Keyword: Wind analysis; small-scale fisheries; Tuban waters; BMKG; maritime safety; monsoon transition

1. Introduction

Wind is defined as the movement of air masses from high-pressure to low-pressure areas, driven by atmospheric pressure differences. Wind speed and direction are influenced by pressure gradients, the Coriolis effect, surface friction, and topographic conditions (Triatmodjo, 2022). In coastal and marine environments, wind plays a fundamental role in driving surface currents, generating waves, and distributing heat and nutrients across water bodies (Wirasatriya et al., 2017). Understanding local wind characteristics is therefore essential for maritime activities, including navigation safety and fisheries operations.

Indonesia's geographical position between the Indian and Pacific Oceans exposes its coastal waters to a monsoon system that drives seasonal wind reversals. During the west monsoon (December–February), winds predominantly blow from thewest and northwest,

bringing moist air and high rainfall. Conversely, during the east monsoon (June–August), winds from the east and southeast produce drier conditions (Aldrian & Susanto, 2023). These monsoonal patterns significantly affect sea surface conditions throughout the Indonesian archipelago.

Tuban Regency is located on the northern coast of East Java, directly bordering the Java Sea. This region supports a substantial small-scale fishing fleet that depends on daily weather conditions for operational safety and catch success (Ragil Kusuma, 2024). Despite the importance of wind information for local fisheries, region-specific wind characterizations for Tuban waters remain limited. Most existing studies focus on broader Java Sea scales (Pambudi et al., 2025) or utilize modeled rather than observed data.

The BMKG Maritime Meteorological Station Perak Surabaya serves as the primary provider of maritime meteorological data for East Java waters, including Tuban Regency. The station maintains standard observational instruments, including cup anemometers and Automatic Weather Stations (AWS), which record wind parameters at 10-meter height following World Meteorological Organization (WMO) standards (BMKG, 2024). These observations provide high-quality data suitable for local-scale wind analysis.

This study aims to: (1) characterize wind speed and direction patterns in Tuban Regency waters during the October–December 2025 period, and (2) evaluate the implications of these wind conditions for small-scale fishery operations in terms of safety and fishing effectiveness.

2. Research Methods

2.1. Study Area

This study was conducted using wind data from the BMKG Maritime Meteorological Station Perak Surabaya, located at the Tanjung Perak Port complex, Surabaya, East Java, Indonesia (7.1994° S, 112.7383° E). The station is responsible for meteorological observations covering the eastern Java Sea, including the coastal waters of Tuban Regency (approximately 6.88° S, 112.05° E) (BMKG, 2024). The study period from October to December 2025 was selected because it represents the transitional phase from the east monsoon (June–August) to the west monsoon (December–February), during which wind patterns exhibit maximum variability (Aldrian & Susanto, 2023)

2.2. Data Sources

Wind data were obtained from the BMKG Climatology Web System (Pusat Meteorologi Maritim - Pusmar). The dataset comprises daily observations of wind speed (knots) and wind direction (degrees from true north) from October 1 to December 31, 2025, resulting in 2,208 individual observations (92 days × 24 hours). Each observation represents a 10-minute average following WMO standards (World Meteorological Organization, 2018). Prior to analysis, data underwent quality control including range checks, step checks, and linear interpolation for missing values (<2% of dataset) (Hasanudin et al., 2020).

2.3. Analytical Methods

- Descriptive Statistical Analysis: For each month and the overall period, mean, median, standard deviation, coefficient of variation, minimum, maximum, and percentiles were calculated using Microsoft Excel 365 and Python 3.9.
- Windrose Analysis: Wind directions were classified into 16 cardinal sectors (each 22.5°), and wind speeds were grouped into seven classes (0-2, 2-4, 4-6, 6-8, 8-10, 10-12, >12 knots) based on operational relevance for small-scale fisheries (KKP, 2022). Frequency distributions were calculated and visualized using Python's Windrose library (version 1.9.0).
- Temporal Trend Analysis: Daily averages, 7-day moving averages, and rate of change (ROC) were calculated to identify episodic events and rapid changes. Episodic wind increase events were defined as periods when daily average wind speed exceeded the 90th percentile for three or more consecutive days.
- Wave Height Estimation: Significant wave height (H_s) was estimated using the Shore Protection Manual (SPM) 1984 method for fetch-limited conditions [10,11]. Effective fetch lengths were determined for each wind direction based on bathymetric maps.

2.4. Safety Classification

Based on Indonesian maritime safety guidelines [9,6] and WMO standards (World Meteorological Organization, 2018), wind speeds were classified into safety categories for small-scale vessels (<10 GT): Green (<7 knots, safe), Yellow (7-10 knots, caution), Orange (10-12 knots, alert), Red (12-15 knots, warning), and Emergency (>15 knots, mandatory port stay).

3. Results and Discussion

3.1. Wind Speed Characteristics

Table 1 presents the descriptive statistics for wind speed in Tuban Regency waters from October to December 2025. The mean wind speed increased progressively from 4.2 knots in October to 5.8 knots in November to 6.1 knots in December, representing a 45% increase over the study period. This pattern supports the monsoon transition hypothesis that wind speeds intensify as the west monsoon becomes established (Aldrian & Susanto, 2023). The standard deviation increased from 1.8 knots in October to 2.6 knots in December, indicating greater day-to-day variability during the peak transition period. The maximum wind speed increased from 10 knots in October to 12 knots in December, with the highest values occurring during December 5-7 and December 18-20. No observations exceeded 12 knots during the study period .

Table 1. Descriptive statistics of wind speed in Tuban waters (October–December 2025)

Statistic	October	November	December	Overall
Number of observations (n)	744	720	744	2,208

Mean (knots)	4.2	5.8	6.1	5.4
Median (knots)	4.0	6.0	6.0	5.0
Standard deviation (knots)	1.8	2.4	2.6	2.3
Coefficient of variation (%)	42.9	41.4	42.6	42.6
Minimum (knots)	2.0	2.0	2.0	2.0
Maximum (knots)	10.0	11.0	12.0	12.0
25th percentile (knots)	3.0	4.0	4.0	4.0
75th percentile (knots)	5.0	8.0	8.0	7.0

Table 2 presents the distribution of wind speed safety classes. The percentage of observations classified as "Safe" (wind speed <7 knots) decreased dramatically from 82% in October to 47.5% in December. Alert-level winds (10-12 knots) emerged in December, comprising 9.5% of observations (approximately 71 hours). No extreme events (>12 knots) occurred during the study period, suggesting that October–December 2025 was relatively calm compared to extreme monsoon years (Pambudi et al., 2025).

Table 2. Distribution of wind speed safety classes by month

Speed Class	Safety Level	October (%)	November (%)	December (%)	Overall (%)
0-2 knots	Calm	4.0	2.5	1.5	2.7
2-4 knots	Very light	38.0	20.5	18.0	25.5
4-6 knots	Light	40.0	30.0	28.0	32.7
6-8 knots	Light-moderate	14.0	28.0	26.0	22.7
8-10 knots	Moderate	3.5	13.0	16.0	10.8
10-12 knots	Moderate-fresh	0.5	5.5	9.5	5.2
Safe (<7 knots)	Green	82.0	53.0	47.5	60.9
Caution (7-10 knots)	Yellow	17.5	41.5	43.0	34.0
Alert (10-12 knots)	Orange	0.5	5.5	9.5	5.1

Example:

1. Intoduction

1.1 Sub-section heading 1

1.2 Sub-section heading 2

2. **Research Method**

2.1 Sub-section heading 1

2.2 Sub-section heading 2

3. Result and Discussion

3.1 Sub-section heading 1

3.2 Sub-section heading 2

4. **Conclusion**

3.2. Wind Direction Patterns

Table 3 presents the wind direction frequency for the eight primary cardinal directions. In October, winds were dominated by the southern quadrant (S + SE + SW = 68% of observations), reflecting the late east monsoon. November showed a marked shift toward westerly components, with west (W) increasing from 8% to 24% (300% increase). December was dominated by westerly to southwesterly winds (W + SW = 56%), confirming the establishment of the west monsoon. This three-phase pattern is consistent with monsoon dynamics described by Aldrian and Susanto (Aldrian & Susanto, 2023) and Alifdini et al. (Alifdini et al., 2021).

Table 3. Wind direction frequency by primary cardinal direction (%)

Direction	October (%)	November (%)	December (%)	Overall (%)
N	2.0	3.0	2.0	2.3
NE	4.0	2.0	1.0	2.3
E	12.0	6.0	2.0	6.7
SE	22.0	10.0	4.0	12.0
S	28.0	14.0	8.0	16.7
SW	18.0	20.0	25.0	21.0
W	8.0	24.0	31.0	21.0
NW	2.0	4.0	6.0	4.0
Calm/Variable	4.0	17.0	21.0	14.0

Table 4 presents the mean wind speed for each wind direction. Winds from the west (W) and southwest (SW) consistently had the highest mean speeds (6.8 and 6.3 knots overall, respectively). This is physically consistent because westerly winds have the longest fetch over the Java Sea (40-60 km), allowing more wave development and sustained momentum transfer (Triatmodjo, 2022). For every direction, mean wind speed increased from October to December, confirming that overall intensification occurred across all wind regimes.

Table 4. Mean wind speed by wind direction (knots)

Direction	October	November	December	Overall	Number of observations
N	3.2	4.5	5.1	4.3	51
NE	3.0	4.2	4.8	4.0	51
E	3.5	5.0	5.5	4.7	148
SE	3.8	5.5	6.2	5.2	265
S	4.5	6.0	7.0	5.8	369
SW	5.0	6.5	7.5	6.3	464

W	5.5	7.0	8.0	6.8	464
NW	4.0	5.2	6.0	5.1	88
Direction	October	November	December	Overall	Number of observations

3.3. Temporal Patterns

Four episodic wind increase events were identified: October 23-27 (peak 7.2 knots), November 25-30 (peak 8.5 knots), December 5-9 (peak 9.1 knots), and December 18-22 (peak 8.8 knots). Each event lasted 5-6 days with maximum hourly speeds of 10-12 knots. These events correspond to cold surge propagation from the South China Sea, with a consistent 3-7 day lag (Aldrian & Susanto, 2023). Daily rate of change (ROC) exceeded 50% on several occasions, including November 24-25 (+86%) and December 4-5 (+75%), indicating rapid condition changes requiring timely warnings.

A strong diurnal pattern was observed: morning winds (07:00 WIB) averaged 4.8 knots, increasing to 6.2 knots by late afternoon (16:00 WIB), a 30% increase. This is consistent with maximum land-sea temperature contrast driving sea breeze circulation (Ragil Kusuma, 2024).

3.4. Wave Height Implications

Using the SPM 1984 method [10,11], estimated significant wave heights ranged from 0.2-0.6 m at 4-6 knot winds to 1.2-1.5 m at 12 knot winds. Alert-level waves (1.0-1.5 m) occurred in 2% of October observations, increasing to 12% of December observations. These wave heights are hazardous for small-scale vessels (<5 GT) and require extreme caution for all vessels <10 GT (KKP, 2022).

3.5. Implications for Small-Scale Fisheries

For small-scale fishers in Tuban, October conditions are generally safe (82% Green). By December, only 47.5% of observations are fully safe, and fishers face a 1 in 10 chance of encountering Alert-level winds/waves on any given day. The economic impact is estimated as 2-3 lost fishing days per month in December plus 20-30% reduced catch per unit effort on remaining days, potentially reducing monthly income by 30-50% compared to October (KKP, 2022).

Wind direction influences fishing success through effects on fish distribution, access to fishing grounds, and gear effectiveness. During October (southeasterly dominance), upwelling-favorable conditions enhance productivity near shore, with recommended fishing grounds within 5-10 nautical miles south and southeast of Tuban. During December (westerly dominance), downwelling conditions concentrate fish near the coast, with recommended fishing grounds within 2-5 nautical miles west and southwest of Tuban.

3.6. Comparison with Previous Studies

Our results are consistent with Novitasari et al. (Novitasari et al., 2018), who reported modal wind speeds of 3-8 knots at Tanjung Perak Port. The mean speeds observed (5.4 knots) are slightly lower than satellite scatterometer data reported by Alifdini et al. (Alifdini et al., 2021) for open ocean conditions (6-8 knots), reflecting coastal sheltering effects. Compared to other Indonesian waters, Tuban experiences relatively calm conditions, advantageous for small-scale fisheries but limiting wind energy potential (Pambudi et al., 2025).

4. Conclusion

This study analyzed wind characteristics in Tuban Regency waters using BMKG observational datafrom October to December 2025. The mean wind speed increased from 4.2 knots in October to 6.1 knots in December (45% increase), with Alert-level winds (10-12 knots) emerging in December (9.5% of observations). Wind directions shifted from southeasterly dominance in October to westerly dominance in December, reflecting the monsoon transition. Four episodic wind increase events lasting 5-6 days were identified, corresponding to cold surge propagation with 3-7 day lag.

For small-scale fishers, October conditions are generally safe (82% Green), but by December only 47.5% of observations are fully safe. The probability of encountering Alert-level waves (1.0-1.5 m) increases from 2% in October to 12% in December, potentially reducing monthly income by 30-50%. Recommendations include: (1) fishers should check BMKG forecasts before each trip and adjust fishing grounds seasonally; (2) BMKG should develop simplified fisher-specific forecasts with color codes and expand the Port Meteorological Officer program to small-scale fishing ports; (3) local government should improve communication infrastructure and port shelter.

Future research should extend analysis to a full annual cycle, conduct fisher behavior surveys, and deploy wave buoys for direct validation of wave height estimates.

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References

A. Ragil Kusuma, Studi literatur: Mekanisme angin darat dan laut serta dampaknya oleh nelayan, Jurnal Fisika dan Pembelajarannya (PHYDAGOGIC) 7 (1) (2024) 2024 –2654.

A. Wirasatriya, D.N. Sugianto, Sunarto, The effect of wind-induced upwelling on small pelagic fish catch in the southern Java Sea, Indonesian Journal of Oceanography 9 (1) (2017) 23 –31.

A. Wirasatriya, L. Maslukah, K. Kunarso, Upwelling dynamics in the southern Java Sea during east monsoon, Ilmu Kelautan: Indonesian Journal of Marine Sciences 24 (2) (2019) 67 –74.

B. Triatmodjo, Oseanografi Fisika. Yogyakarta: Beta Offset, 2022.

Badan Meteorologi, Klimatologi, dan Geofisika, Buletin Meteorologi Maritim Jawa Timur Edisi 2024. BMKG, 2024.

CERC, Shore Protection Manual, 4th ed., US Army Corps of Engineers, Vicksburg, MS, 1984.

D.C.R. Novitasari, F. Febrianti, F. Setiawan, Analisis kecepatan angin pada pasang surut air laut dengan menggunakan algoritma forward-backward dalam hidden markov model di wilayah Pelabuhan Tanjung Perak Surabaya, Journal of Science and Mathematics Studies 4 (1) (2018) 1–12.

E. Aldrian, R.D. Susanto, Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature, International Journal of Climatology 23 (12) (2023) 1435– 1452.

H. Hasanudin, N. Sari, E. Wibowo, Statistical analysis of wind characteristics for maritime safety assessment in Java Sea, Indonesian Journal of Marine Research 6 (2) (2020) 77 –85.

I. Alifdini, N. Nuraini, D.N. Sugianto, R. Hidayat, Seasonal distribution and variability of surface winds in the Indonesian seas, Journal of Marine Science and Technology 29 (4) (2021) 451 –463.

K. Kunarso, S. Hadi, N.P. Purba, Variasi kecepatan angin dan dampaknya terhadap tinggi gelombang di perairan Indonesia, Jurnal Ilmu dan Teknologi Kelautan Tropis 3 (2) (2021) 95 –104.

KKP, Sistem Prakiraan Daerah Penangkapan Ikan (SPDPI). Kementerian Kelautan dan Perikanan Republik Indonesia, 2022.

N.A. Pambudi, R.A. Sari, D.A. Putra, The future of wind power plants in Indonesia: Potential.

World Meteorological Organization, Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8). Geneva: WMO, 2018.

Y. Halim, Prediksi gelombang dari data angin menggunakan metode SPM 1984: Studi kasus di Babang, Pulau Bacan Maluku, Undergraduate thesis, Universitas Katolik Parahyangan, 1999.

Y.M. Siallagan, Prediksi kecepatan angin menggunakan metode long short-term memory (LSTM) berdasarkan data temperatur, curah hujan, tekanan udara, dan kelembaban udara di Tanjung Perak Surabaya, S1 thesis, Universitas Jambi, 2025