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Wind pattern analysis at Bandaranaike international airport (2019-2023): temporal variability and dominant wind directions

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सार – यह अध्ययन कटुनायके अंतर्राष्ट्रीय हवाई अड्डे पर हवा के पैटर्न के विश्लेषण पर केंद्रित है, जो उड़ान सुरक्षा और दक्षता में एक महत्वपूर्ण कारक है। हवा की गति और दिशा का उड़ान संचालन पर महत्वपूर्ण प्रभाव पड़ता है, विशेष रूप से टेक-ऑफ और लैंडिंग के दौरान। इस शोध का उद्देश्य हवाई अड्डों से प्राप्त अवलोकन डेटा का उपयोग करके पांच वर्षों (2019-2023) की अवधि में हवा के व्यवहार की व्यापक समझ प्रदान करना है। ये निष्कर्ष विमानन सुरक्षा में सुधार, रनवे के उपयोग में दक्षता बढ़ाने और कटुनायके अंतर्राष्ट्रीय हवाई अड्डे पर परिचालन योजना में सुधार के लिए मूल्यवान अंतर्दृष्टि प्रदान करते हैं। यह अध्ययन विमानन में प्रतिकूल मौसम स्थितियों से जुड़े जोखिमों को कम करने के लिए सटीक मौसम पूर्वानुमान के महत्व पर भी जोर देता है।

परिणामों से पता चलता है कि वर्ष के आरंभिक और अंतिम महीनों में उत्तरपूर्वी मानसून का प्रभुत्व रहता है, जबकि दक्षिण-पश्चिमी मानसून मई से सितंबर तक रहता है। हवा की गति आमतौर पर 3-7 समुद्री मील के बीच होती है, जो उत्तरपूर्वी मानसून के दौरान सबसे अधिक होती है। दक्षिण-पश्चिमी मानसून मुख्यतः दक्षिण-पश्चिम से तेज हवाएँ लाता है, जबकि उत्तरपूर्वी मानसून उत्तर-पूर्व से अपेक्षाकृत शांत हवाएँ लाता है।

ये निष्कर्ष विमानन संचालन के लिए बहुमूल्य जानकारी प्रदान करते हैं, जिसमें रनवे के उपयोग, उड़ान सुरक्षा और परिचालन योजना से संबंधित अंतर्दृष्टि शामिल हैं। विस्तृत पवन प्रोफाइल स्थापित करके, यह अध्ययन स्थानीय मौसम विज्ञान संबंधी ज्ञान को बढ़ाता है, पूर्वानुमान मॉडल के विकास में योगदान देता है और अल्पकालिक से मध्यम अवधि के पवन पूर्वानुमानों की सटीकता को सुनिश्चित करता है। यह विश्लेषण अंततः विभिन्न पवन स्थितियों में हवाई अड्डे के प्रबंधन और परिचालन दक्षता में सुधार करने में सहायक होता है।

ABSTRACT. This study focuses on the analysis of wind patterns at Bandaranaike International Airport, which is a key factor in flight safety and efficiency. Wind speed and direction have a significant impact on flight operations. Especially during take-off and landing. The objective of this research is to provide a comprehensive understanding of wind behavior over a five-year period (2019–2023) using observational data from airports. These findings provide valuable insights to improve aviation safety. Increase efficiency in using the runway and improving operational planning at Bandaranaike International Airport. The study also emphasizes the importance of accurate weather forecasts to reduce risks associated with adverse weather conditions in aviation.

The consequences show that the northeast monsoon dominates within the early and past due months of the year, whilst the southwest monsoon prevails from May to September. Wind speeds are typically among 3–7 knots, with the very best prevalence at some point of the northeast monsoon. The southwest monsoon brings stronger winds predominantly from the southwest, whilst the northeast monsoon introduces enormously calmer winds from the northeast.

The findings provide valuable information for aviation operations, including insights for runway utilization, flight safety, and operational planning. By establishing a detailed wind profile, this study enhances local meteorological knowledge, contributing to the development of predictive models and supporting the accuracy of short- to medium-term wind forecasts. This analysis ultimately aids in improving airport management and operational efficiency under varying wind conditions.

Key words – Wind analysis, Bandaranaike international airport, Seasonal wind patterns, Airport safety.

1. Introduction

Sri Lanka is an island nation located in the Indian Ocean, southeast of the Indian subcontinent, primarily situated between latitudes 5°55' N and 9°51' N and longitudes 79°41' E and 81°53' E. Its geographical features are diverse, ranging from coastal plains to central highlands, giving the country a rich natural landscape.

Sri Lanka has some predominant international airports that function gateways for travelers coming to and from the island. The important international airport in Sri Lanka is Bandaranaike International Airport that is placed in Katunayake, near the capital metropolis of Colombo, inside the Western province.

In addition to imparting connections to several overseas places, consisting of the Middle East, Asia, Europe, and beyond, it manages the majority of the nation's worldwide air site visitors.

Aviation is enormously regulated to make sure safety. Rules for airspace control, pilot training, plane preservation, and protection protocols may be mounted by using agencies which include the European Aviation Safety Agency (EASA), Federal Aviation Administration (FAA), and International Civil Aviation Organization (ICAO).

Meteorology plays a crucial role in aviation safety, as weather conditions significantly impact flight operations. Understanding and predicting atmospheric phenomena helps ensure safe and efficient flights, as weather can influence every phase of a flight from take-off and cruising to landing.

Pilots and airline operations staff use comprehensive weather forecasts to devise routes prior to each flight. Pilots may ensure more secure and greater seamless flights via heading off risky climate situations consisting of thunderstorms, turbulence, and sturdy winds with the aid of accurate meteorological facts.

Understanding wind direction and speed is crucial for figuring out the most fuel-efficient flight routes. Favorable tailwinds can lessen flight time, whilst headwinds can growth fuel intake. Strong crosswinds at some point of take-off or touchdown may additionally require changes to runway selections or maybe postponing the flight.

Aviation authorities global depend on historical and actual-time wind information for flight planning and runway management. Wind statistics analysis consists of inspecting both floor and higher – degree winds, as these elements effect flight paths, fuel intake, and runway choice (ICAO, 2007). Several studies have focused at the analysis of wind traits at airports, together with the works via Rojek *et al*. (2019), who studied wind route variability at airports to recognize the impact on operational performance. Airport meteorological conditions strongly influence operational efficiency and delay management (Bazargan & Kaighobadi, 2017).

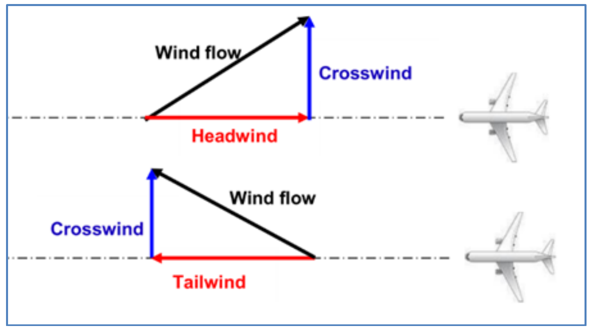


Fig. 1. Aircraft headwind, tailwind and crosswind
Source: Training Manual (International Virtual Aviation Organization)

At airports positioned close to coastal regions, including Bandaranaike International Airport at Katunayake, nearby geographical capabilities like sea breezes and proximity to water our bodies appreciably have an effect on wind styles. A look at with the aid of Chand *et al*. (2017) on Indian airports close to coastal areas located that sea breezes regularly reason substantial variations in wind speed and path, affecting runway operations. Diurnal variations of wind speed are well documented in airport meteorological studies (Smith et al., 2014).

The seasonal variability of winds because of monsoon cycles in South Asia considerably impacts aviation operations. Katunayake, placed on the western coast of Sri Lanka, is mainly stricken by the southwest monsoon, which brings more potent winds, and the northeast monsoon, characterized with the aid of extraordinarily calmer winds. According to WMO (2020), this variability requires continuous tracking to ensure that airport operations continue to be efficient and secure.

Mainly, there are three kinds of winds affected while handling aircraft which are tailwind, headwind, and crosswind (Fig. 1).

A tailwind is a wind that blows in the same direction as the aircraft’s flight path (Fig. 2). It comes from behind the aircraft, pushing it forward

The aircraft's floor velocity is raised by tailwinds without using extra engine power. This result in speedier travel times and less fuel use. Particularly on long-haul

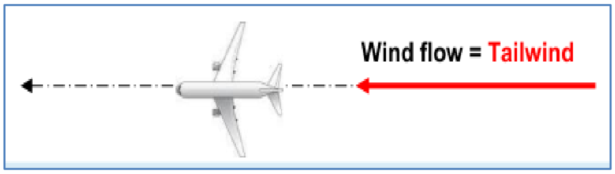


Fig. 2. Aircraft Tailwind
Source: Training Manual (International Virtual Aviation Organization)

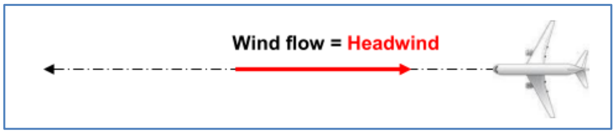


Fig. 3. Aircraft Headwind
Source: Training Manual (International Virtual Aviation Organization)

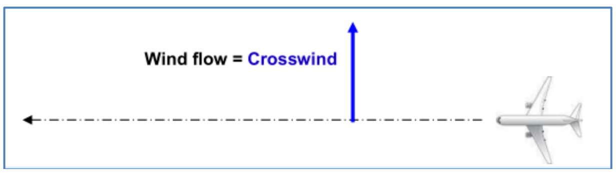


Fig. 4. Aircraft Crosswind
Source: Training Manual (International Virtual Aviation Organization)

flights, tailwinds let the airplane cover more ground in less time, which reduces the duration of the flight.

Tailwinds are helpful when cruising, but they can make landings more difficult because they force the airplane to slow down over greater distances, which increases landing roll.

Tailwind situations play a full-size position in aviation safety, as they are frequently related to injuries, particularly runway overruns for the duration of landing (van Es & Karwal, 2001). An research into tailwind-related accidents (van Es & Karwal, 2001) highlights that tailwinds make a contribution predominantly to overrun incidents, with the threat increasing when the runway is moist or contaminated. Additionally, a majority of those injuries came about while tailwinds surpassed 10 knots.

A headwind is a wind that blows directly against the aircraft's flight path, meaning the wind comes from the front (Fig. 3).

Although the velocity (speed relative to the air) remains constant, headwinds reduce the plane's floor speed. In this manner, the plane takes longer to get to its destination. Headwinds cause the airplane to work harder and stay in the air longer, which results in a lower floor speed and an increase in gas input. Although headwinds have drawbacks when cruising, they are typically advantageous for take-off and landing. Headwinds provide more lift at lower ground speeds, which helps aircraft take off more easily and land with a shorter roll on the runway.

A crosswind is a wind that blows perpendicular to the aircraft's flight path or runway (Fig. 4), coming from the side.

Crosswinds are particularly dangerous during take-off and landing because they have the potential to divert the aircraft from its intended course. Pilots aim to maintain runway alignment by modifying the aircraft's heading to account for crosswinds. Crosswinds may cause challenging or dangerous take-offs and landings if they surpass specific thresholds for a given aircraft. Pilots can choose trade runways or airports when crosswinds are too high, and airports frequently report crosswind conditions.

The Federal Aviation Administration (FAA, 2012) specifies that a runway's orientation should offer 95% coverage based on annual wind situations. This manner that the crosswind issue must continue to be underneath the allowable crosswind component (ACC) for 95% of the time. If an analysis of wind records indicates that a runway does now not meet this 95% coverage, a second runway, normally oriented otherwise (e.g., perpendicular to the first), may be vital to attain the required insurance for both runways combined. Similarly, the European Aviation Safety Agency (EASA, 2011) mandates that runways have to be oriented in this sort of manner that the usability factor, described as the percentage of time the runway is operable for the intended aircraft, is at least 95%. The phrases "coverage" and "usability factor" are consequently taken into consideration equal in this context.

2. Data and methodology

2.1. *Research strategies and techniques*

The Bandaranaike International Airport Meteorological Office provided the necessary 5-year secondary data of wind speed and wind direction on a daily and hourly basis with hourly METAR data for the period of January 2019 to December 2023.

Wind speed and direction were measured by a AWS Anemometer (Model: WMT 700) installed at the Katunayake Meteorological Station. The instrument has an accuracy of ±0.5 knots for wind speed and ±5° for wind direction.

Data processing and analysis were carried out using Python (v3.10) and Microsoft Excel 2021. In Python pandas, numpy, math, matplotlib and windrose, libraries were used to respectively data cleaning and manipulation, graphical plotting, generating wind rose diagrams and trigonometric calculations of wind components.

2.2. *Research Variable*

This study does not attempt to predict flight performance but aims to characterize the wind environment at Bandaranaike International Airport over five years. Raw meteorological inputs are the independent variables, *i.e*., wind speed in knots and wind direction in degrees from true north. Derived outputs were obtained from these, which are the dependent variables of the study. Among these are the frequency distribution of wind direction and wind speed, monthly and yearly construction of wind roses, the cardinal sector percentage contribution of winds, and headwind, tailwind, and crosswind component computations as referenced to the main runway of the airport. Thus, the dependent variables are not the measurements themselves but analysis results derived from the underlying wind measurements.

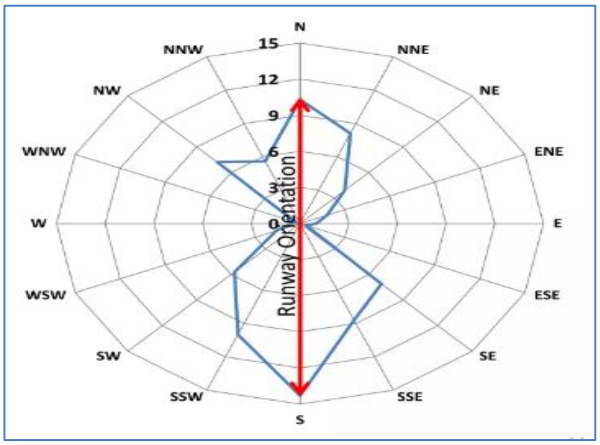


Fig. 5. Windrose Template
Source: https://www.slideshare.net/slideshow/wind-rosepdf/252297976

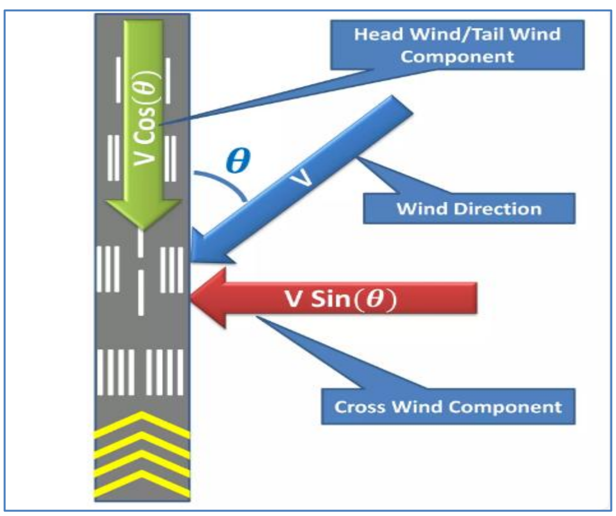


Fig. 6. Crosswind Calculation
Source: https://www.slideshare.net/slideshow/wind-rosepdf/252297976

2.3. *Processing and data analysis*

2.3.1. *Windrose method*

A wind rose is a graphical tool used to represent the distribution of wind speed and direction at a specific location over a defined period. It provides a clear visualization of how often winds blow from particular directions and at what speed, typically represented using radial bars extending from the centre of a circle.

In order to identify the wind direction with a significant dominant wind speed, the average direction and surface wind speed are found in the wind rose analysis stages. The wind speed is indicated by the circles on the template, and the direction or degree of wind gusts is indicated by the radial lines. Two circular segments and two radial lines that indicate different percentages of the wind speed and direction period surround each cell. METAR data on wind direction and speed from January 2019 to December 2023 will be utilized as input for wind rose analysis.

2.3.2. *Wind direction and Speed as percentage*

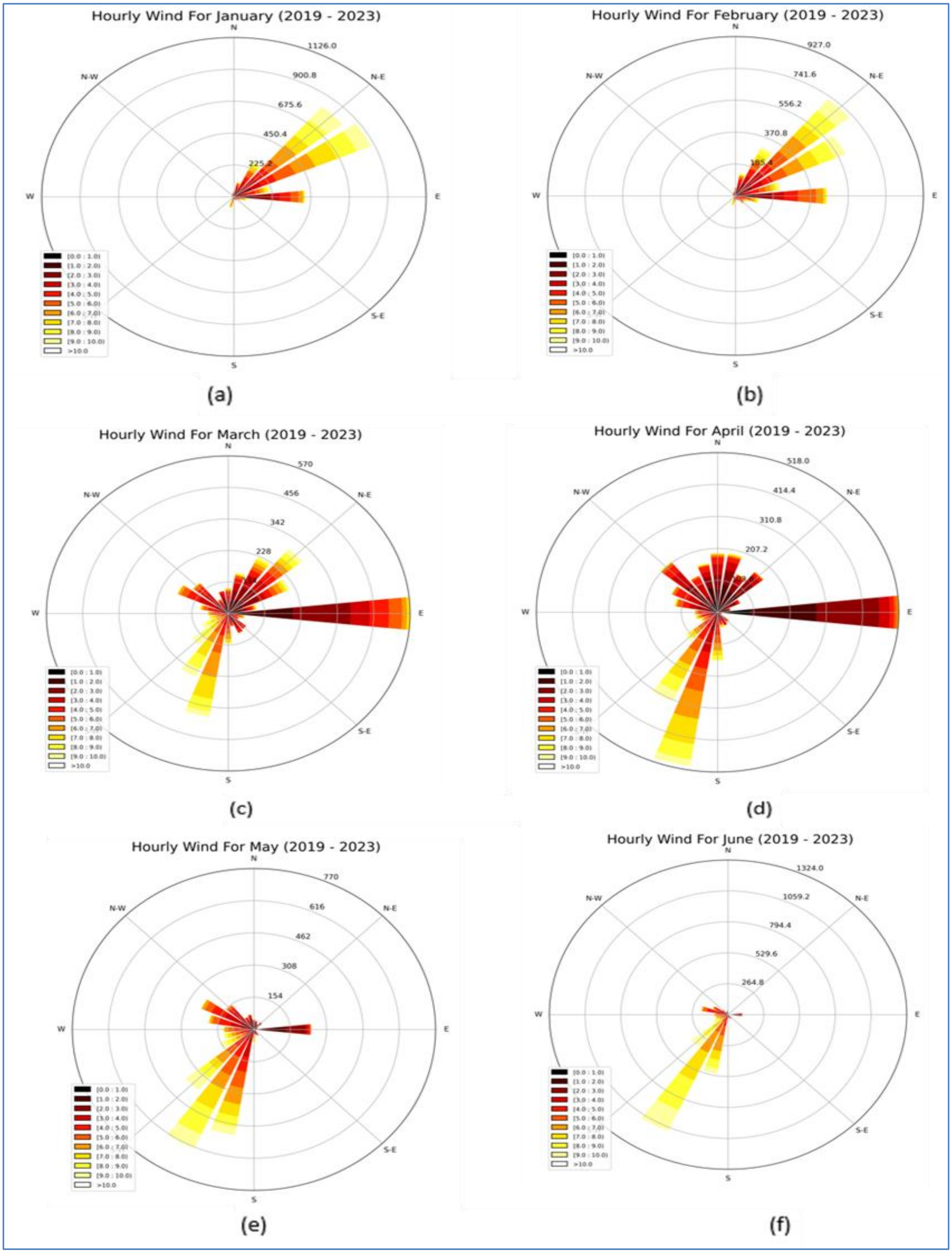
The wind speeds are categorized into various ranges, each expressed as a percentage of the total observations. The categories are designed based on speed ranges (*e.g*., 0-1 knots, 1-3 knots, *etc*.), showing how often the wind falls into each speed category.

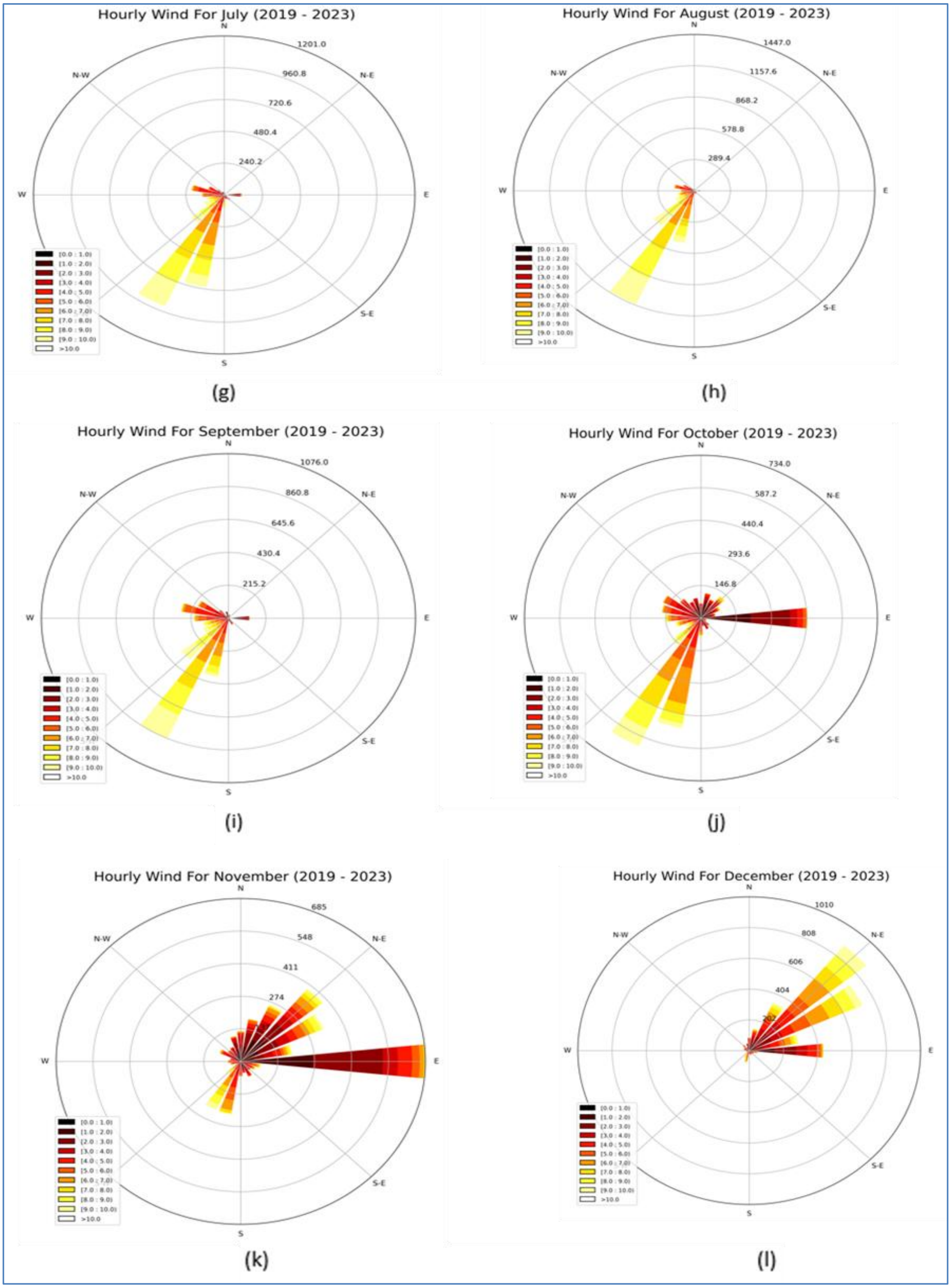
The wind direction bins are adjusted for correct range matching cardinal directions: N (North): Between 337.5° and 22.5°, NE (Northeast): Between 22.5° and 67.5°, E (East): Between 67.5° and 112.5°, SE (Southeast): Between 112.5° and 157.5°, S (South): Between 157.5° and 202.5°, SW (Southwest): Between 202.5° and 247.5°, W (West): Between 247.5° and 292.5°, NW (Northwest): Between 292.5° and 337.5°. Each directional sector is presented as a percentage of the total wind observations, showing which direction dominates during the study period.

2.3.3. *Runway orientation and wind components*

At Bandaranaike International Airport, the principal runway 04/22 has headings of 037° and 217° (true north). These orientations were used as reference axes for all wind component calculations.

A consequent vector obtained from the runway's right angle is the crosswind component. The wind speed multiplied by the sinusoidal trigonometry between the runway and the wind direction. Fig. 6 displays examples of computations for the crosswind component.


Hourly Wind For January (2019 - 2023)
N
N-E
E
S-E
S
W
N-W
1126.0
900.8
675.6
450.4
225.2
[0.0 : 1.0)
[1.0 : 2.0)
[2.0 : 3.0)
[3.0 : 4.0)
[4.0 : 5.0)
[5.0 : 6.0)
[6.0 : 7.0)
[7.0 : 8.0)
[8.0 : 9.0)
[9.0 : 10.0)
>10.0
(a)
Hourly Wind For February (2019 - 2023)
927.0
741.6
556.2
370.8
185.4
(b)
Hourly Wind For March (2019 - 2023)
570
456
342
228
(c)
Hourly Wind For April (2019 - 2023)
518.0
414.4
310.8
207.2
(d)
Hourly Wind For May (2019 - 2023)
770
616
462
308
154
(e)
Hourly Wind For June (2019 - 2023)
1324.0
1059.2
794.4
529.6
264.8
(f)



Figs. 7(a-l). Windrose for Months(a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November and (l) December

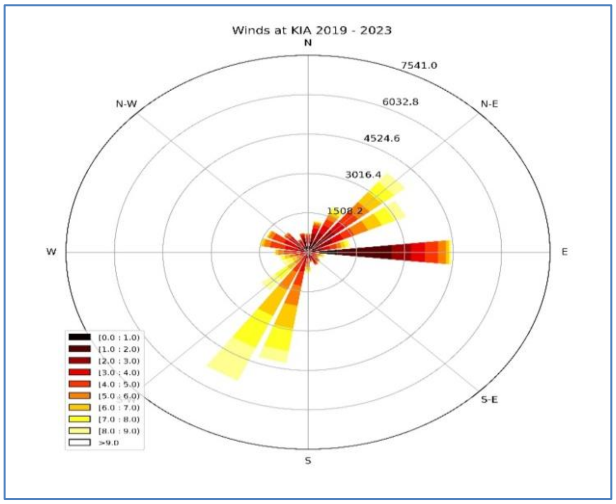


Fig. 8. Whole Wind Rose (2019-2023)

Wind Speed (WS): The actual speed of the wind.

Direction (WD): The direction from which the wind is coming (in degrees from true north).

Runway Heading (RH): The direction of the runway the aircraft is using (in degrees from true north).

First, calculate the wind angle (θ) between the wind direction and the runway heading:

$$\theta = WD - RH$$

If the angle (θ) is greater than 180°, subtract 360° to bring it within the correct range. Headwind/Tailwind Component

$$\text{Headwind Component} = WS \times \cos(\theta)$$

$$\text{Tailwind Component} = -(\text{Headwind Component})$$

If the result is positive, the crosswind is from the right**.**
If the result is negative, the crosswind is from the left.

3. Results and discussion

3.1. *Windrose*

This wind rose demonstrates the distribution of both wind speed and direction, highlighting the dominant wind patterns and their intensities over this time. Such visualizations are valuable for understanding local wind climatology, which is crucial for various applications, including aviation, runway design, and meteorological assessments.

As shown in Fig. 7 provides a visualization of surface hourly wind data at Bandaranaike International Airport for the period from January 2019 to December 2023.

At Bandaranaike International Airport, the average wind direction in January is 66.8% from the Northeast. In February, 57.5% of the wind blows from the Northeast and 24.1% from the East. In March, 20.87% of the wind comes from the Northeast and 19.28% from East. The southern, south-western and North-eastern winds were respectively 20.08%, 14.77% and 10.47% in April. The Southwest and South are responsible for 42.51% and 17.34% of the average wind in May. The southwest and south wind speeds in June were 58.72% and 17.3%. In July, 50.45% of the wind blows from the southwest and 24.4% from the south. In August, the wind comes from the Southwest at 63.57% and 16.07% wind comes from the South. The wind direction in September is 52.52% from the southwest and 17.47% from the West. In October, 28.69% of the wind comes from the southwest and 17.23%, 11.84% were respectively from South and west. In November, 28.19%, 26.52% and 8.42% of the winds come from the Northeast, East and Southwest. In December, North-eastern and Eastern winds were respectively 58.17% and 21.23%.

The average wind speed was 3-7 knots with the percentage 43.2% in January, 47.3% in February, 44.3% in March, 39% in April, 42.4% in May, 36.3% in June, 38.3% in July, 34.9 % in August, 40.1 % in September, 44.6% in October, 40.9% in November and 47.5% in December.

The Windrose, as shown in Fig. 8, indicates that the majority of the wind patterns at Bandaranaike International Airport for the period from Jan 2019 to Dec 2023.

The wind rose indicates that the majority of the wind patterns during this time period are from the east and northeast, which is the predominant wind direction at KIA. These directions are crucial for operational concerns, especially in aviation, since they are primarily linked to stronger winds (6 knots and higher). Other directions, particularly westward and southerly, where wind speeds hardly ever surpass 5 knots, are typically the source of weaker winds.

Regarding the impact of monsoonal and inter-monsoonal winds on wind flow over the island, the predominance of easterly winds is consistent with Sri Lanka's regional climatologically patterns. A possible seasonal or diurnal influence on wind intensity is suggested by the variance in wind speeds, with stronger winds most likely occurring at particular times of the day or year.

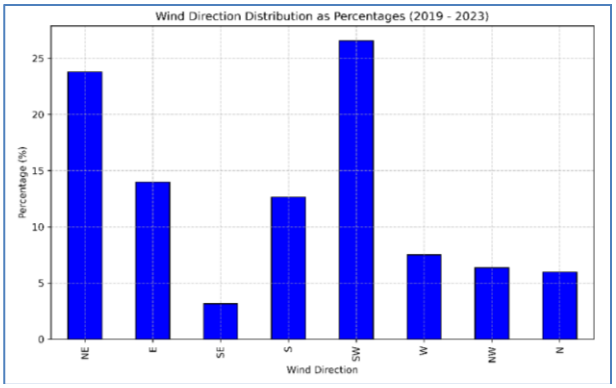


Fig. 9. Wind distribution as Percentage 2019-2023

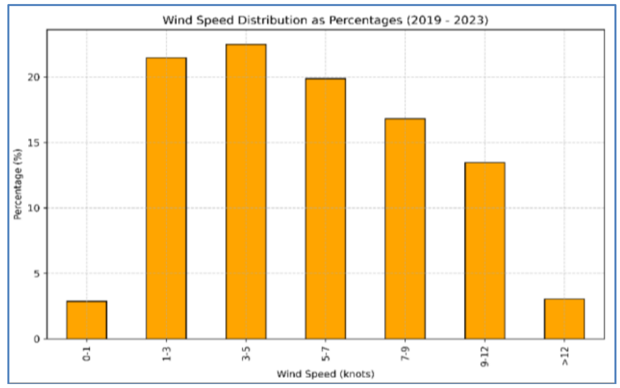


Fig. 10. Wind Speed as Percentage 2019-2023

3.2. *Wind direction and speed as percentage*

As shown in Fig. 9, the bar chart representation illustrates the percentage distribution of different wind directions at Bandaranaike International Airport for the period from January 2019 to December 2023. This approach provides a clear understanding of how directions vary, making it easier to interpret wind direction for Bandaranaike International Airport.

As shown in Fig. 10, the bar chart representation illustrates the percentage distribution of wind speed at Bandaranaike International Airport for the period from January 2019 to December 2023. This approach provides a clear understanding of how wind speeds vary, making it easier to interpret wind speed for Bandaranaike International Airport.

According to the above figures, the wind direction throughout the whole year as Southwest 26.56 %, Northeast 23.79 %, East 13.97 %, South 12.65 %, and West 7. 5 %, Northwest 6.35 %, North 5.9 % and Southeast 3.16 %.

Wind speed spread throughout the year as between 0-1 knots was 2.86 %, between 1-3 knots was 21.46 %, between 3-5 knots was 19.86 %, between 7-9 knots was 16.87 %, between 9-12 knots was 13.16 % and higher than 12 knots was 3.04 %.

3.3. *Monthly average wind speed and direction over time*

Fig. 11 represents the Monthly Average Wind Speed and Direction Over Time at Bandaranaike International Airport from January 2019 to 2023, with the data split by the hour of the day (UTC**)**.

According to the above figures, the red solid line represents the average windspeed in knots over the 24-hour period and the red dashed line represents the mean wind speed. Meanwhile, the blue solid line represents the Wind speeds fluctuate significantly over the hour of the day. The wind speed peaks between 8 and 10 UTC at about 8 knots, after increasing between 5 and 12 UTC. The afternoon sees a sharp drop in wind speed, with values of about 5 knots, reaching a minimum between 21 and 03 UTC. The average wind speed in January and February is almost 6 knots. The lowest average wind speed throughout this time frame, which corresponds to April, is 3.7 knots. average wind direction in degrees and the blue dashed line indicates the mean wind direction.

There is also a noticeable change in the average wind direction throughout the day. The wind direction increases significantly throughout the first four months, starting in the early morning (about 4 to 6 UTC), and reaches a maximum of roughly 90 degrees (east) between 9 and 10 UTC.

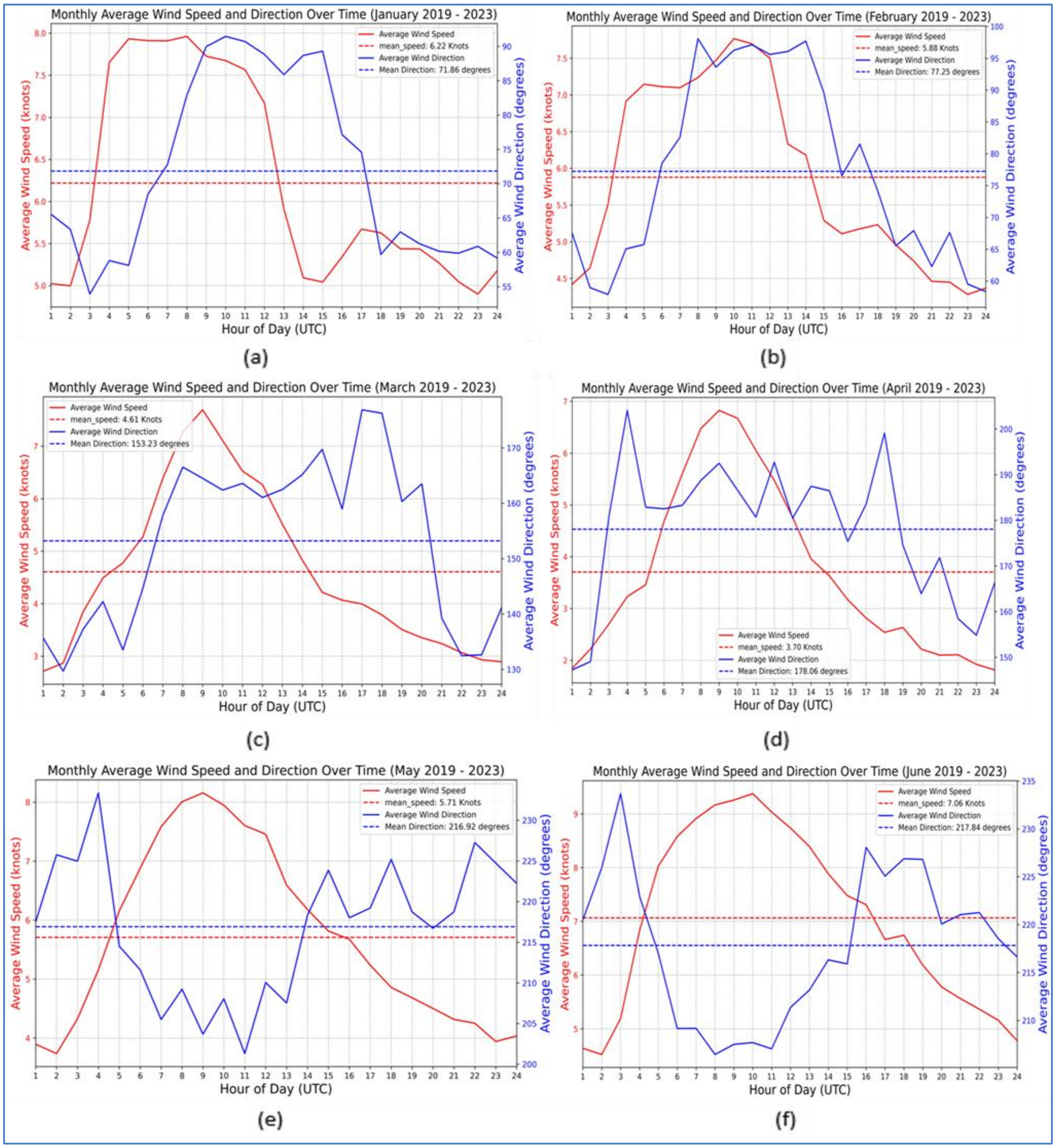
Stronger easterly winds are indicated by the wind direction trending towards 90 degrees when the wind speeds are at their peak, which is between 7 and 12 UTC.

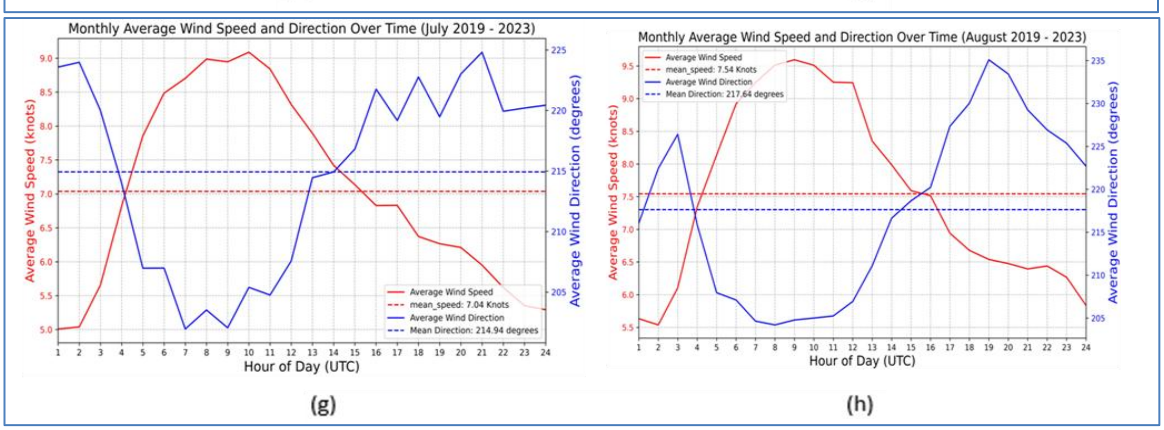
Conversely, when wind speeds are lower (especially in the afternoon), the wind direction changes from 90 degrees to more like 60 degrees (east-northeast).

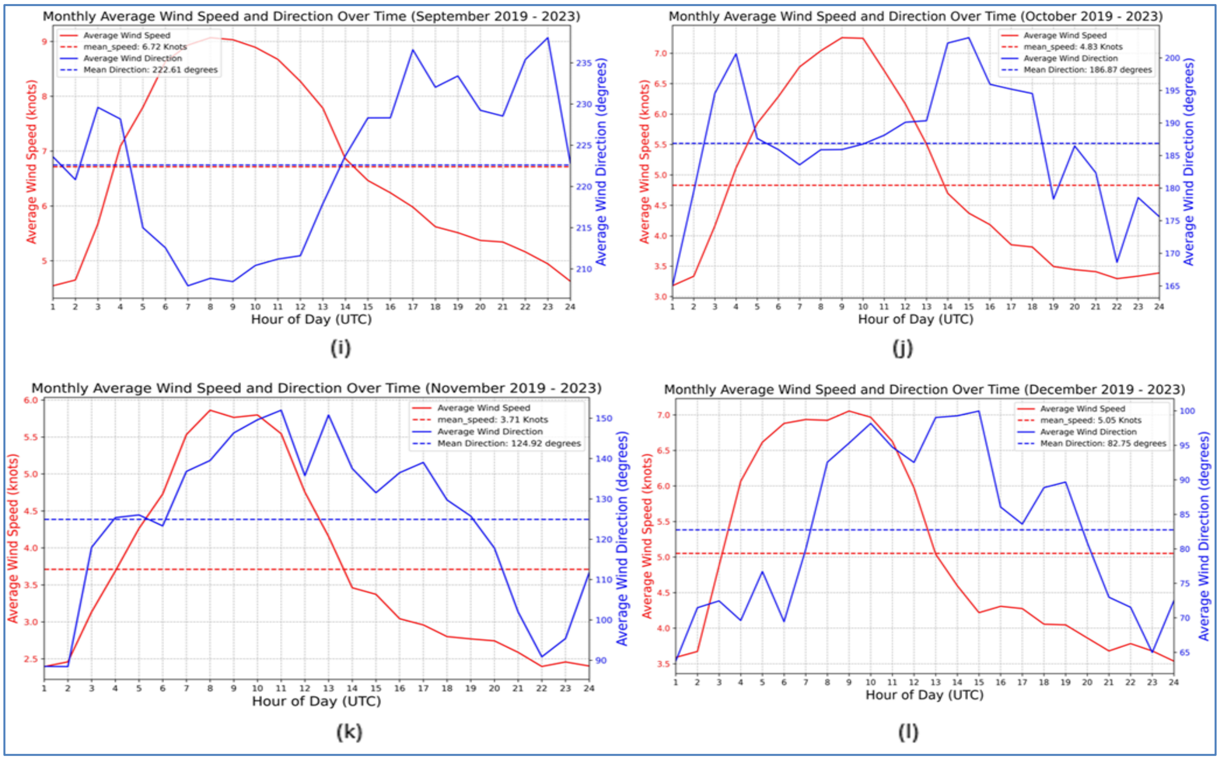
3.4. *Headwind and tailwinds components*

As shown in Fig. 12, provides a visualization of headwind or tailwind at Bandaranaike International Airport for the period from January 2019 to December 2023. The y axis represents the headwind or tailwind in knots and the x axis represents the hour of the day in UTC, from 1 to 24, indicating how the headwind and tailwind change throughout the day.

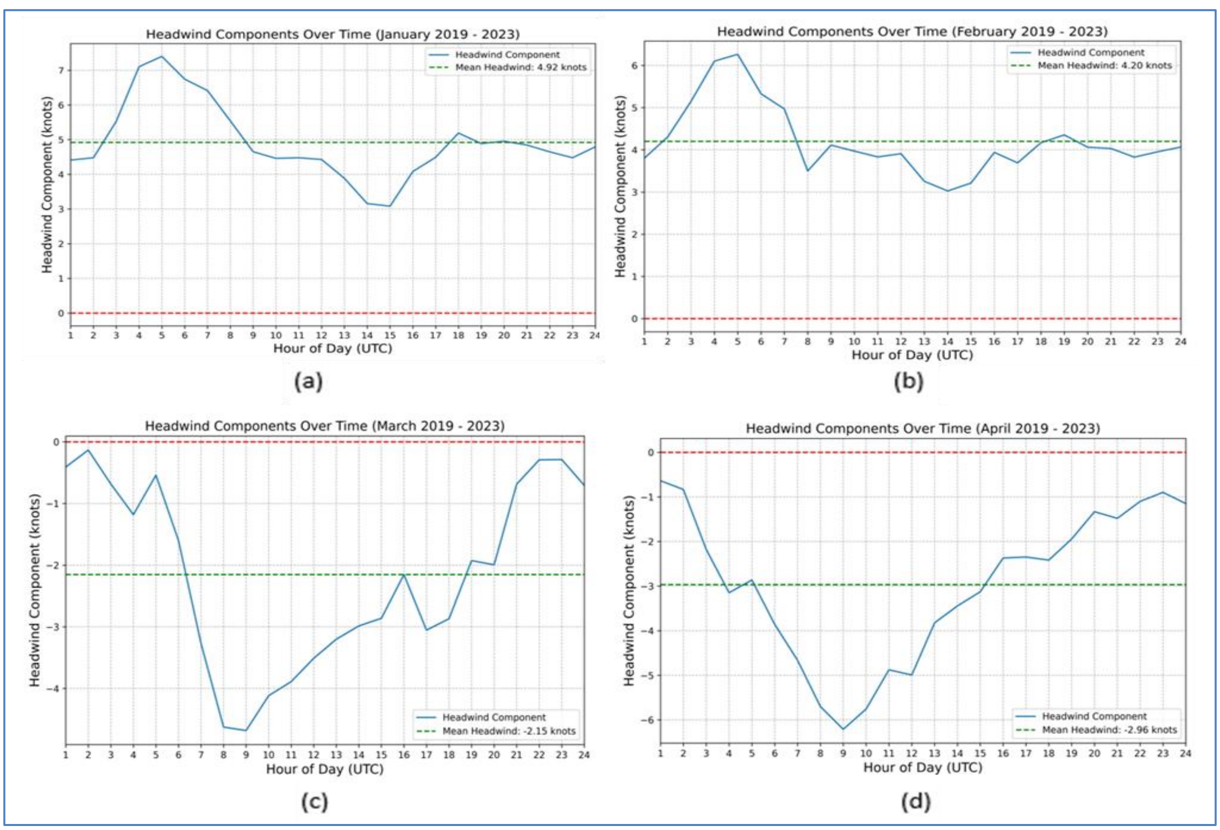
The green dashed line marks the mean headwind or tailwind for the period from 2019 to 2023. The solid blue

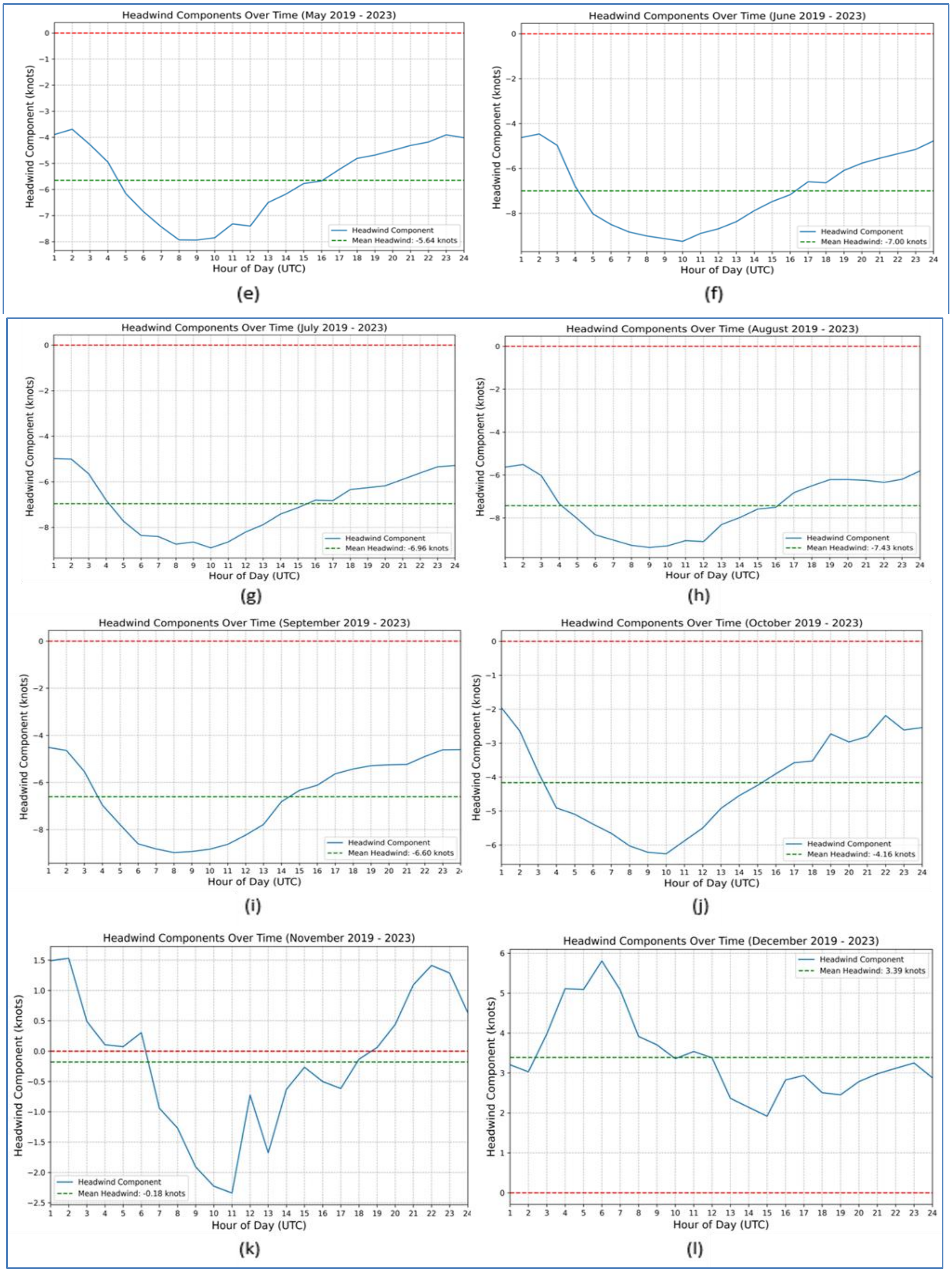

Monthly Average Wind Speed and Direction Over Time (January 2019 - 2023)
Average Wind Speed
mean_speed: 6.22 Knots
Average Wind Direction
Mean Direction: 71.86 degrees
Average Wind Speed (knots)
Average Wind Direction (degrees)
Hour of Day (UTC)
(a)
Monthly Average Wind Speed and Direction Over Time (February 2019 - 2023)
Average Wind Speed
mean_speed: 5.88 Knots
Average Wind Direction
Mean Direction: 77.25 degrees
Average Wind Speed (knots)
Average Wind Direction (degrees)
Hour of Day (UTC)
(b)
Monthly Average Wind Speed and Direction Over Time (March 2019 - 2023)
Average Wind Speed
mean_speed: 4.61 Knots
Average Wind Direction
Mean Direction: 153.23 degrees
Average Wind Speed (knots)
Average Wind Direction (degrees)
Hour of Day (UTC)
(c)
Monthly Average Wind Speed and Direction Over Time (April 2019 - 2023)
Average Wind Speed
mean_speed: 3.70 Knots
Average Wind Direction
Mean Direction: 178.06 degrees
Average Wind Speed (knots)
Average Wind Direction (degrees)
Hour of Day (UTC)
(d)
Monthly Average Wind Speed and Direction Over Time (May 2019 - 2023)
Average Wind Speed
mean_speed: 5.71 Knots
Average Wind Direction
Mean Direction: 216.92 degrees
Average Wind Speed (knots)
Average Wind Direction (degrees)
Hour of Day (UTC)
(e)
Monthly Average Wind Speed and Direction Over Time (June 2019 - 2023)
Average Wind Speed
mean_speed: 7.06 Knots
Average Wind Direction
Mean Direction: 217.84 degrees
Average Wind Speed (knots)
Average Wind Direction (degrees)
Hour of Day (UTC)
(f)


Monthly Average Wind Speed and Direction Over Time (July 2019 - 2023)
Average Wind Speed
mean_speed: 7.04 Knots
Average Wind Direction
Mean Direction: 214.94 degrees
Average Wind Speed (knots)
Average Wind Direction (degrees)
Hour of Day (UTC)
(g)
Monthly Average Wind Speed and Direction Over Time (August 2019 - 2023)
Average Wind Speed
mean_speed: 7.54 Knots
Average Wind Direction
Mean Direction: 217.64 degrees
Average Wind Speed (knots)
Average Wind Direction (degrees)
Hour of Day (UTC)
(h)

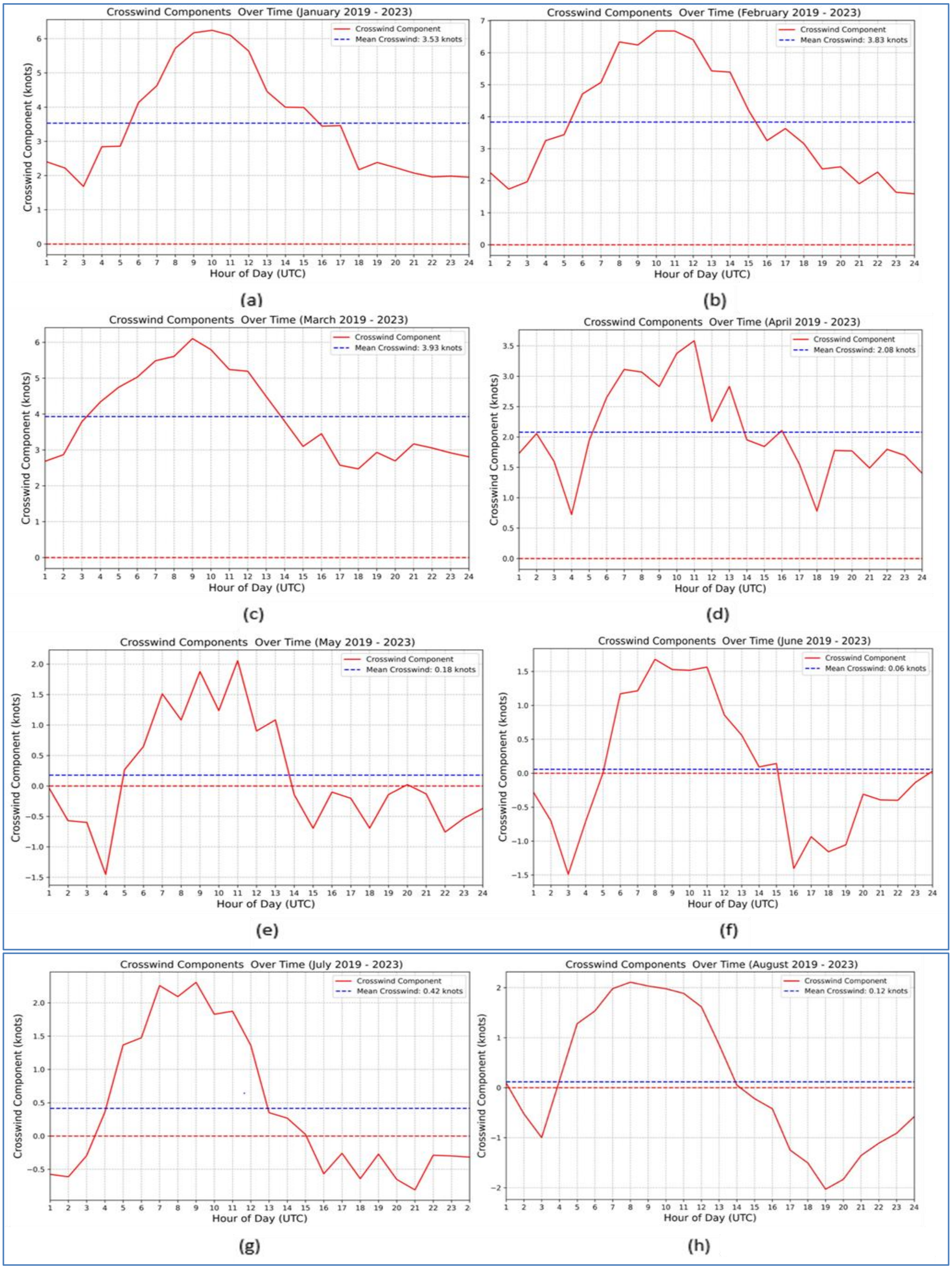


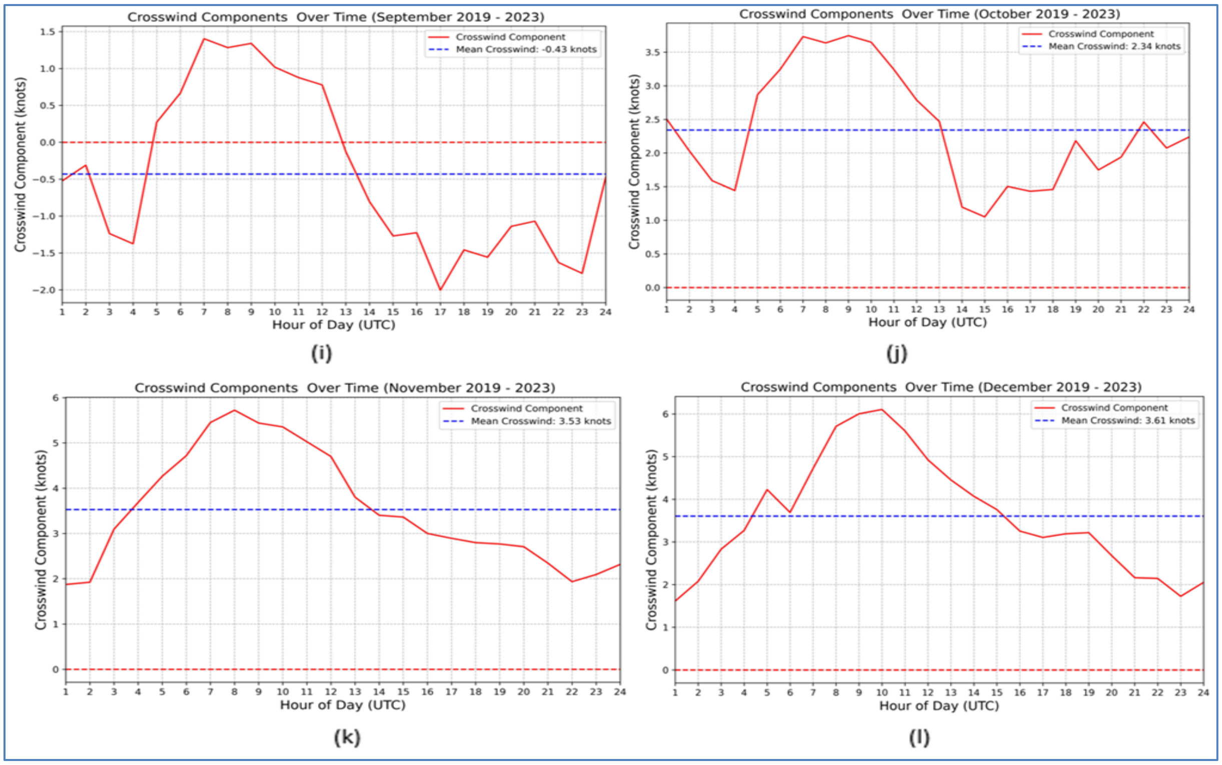
Figs.11(a-l). Wind Speed and Direction over the time for Months (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November and (l) December





Figs. 12(a-l). Headwind and tailwind over the time (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July, (h) August, (i) September, (j) October, (k) November and (l) December


Crosswind Components Over Time (January 2019 - 2023)
Crosswind Component
Mean Crosswind: 3.53 knots
Crosswind Component (knots)
Hour of Day (UTC)
(a)
Crosswind Components Over Time (February 2019 - 2023)
Crosswind Component
Mean Crosswind: 3.83 knots
Hour of Day (UTC)
(b)
Crosswind Components Over Time (March 2019 - 2023)
Crosswind Component
Mean Crosswind: 3.93 knots
Crosswind Component (knots)
Hour of Day (UTC)
(c)
Crosswind Components Over Time (April 2019 - 2023)
Crosswind Component
Mean Crosswind: 2.08 knots
Crosswind Component (knots)
Hour of Day (UTC)
(d)
Crosswind Components Over Time (May 2019 - 2023)
Crosswind Component
Mean Crosswind: 0.18 knots
Crosswind Component (knots)
Hour of Day (UTC)
(e)
Crosswind Components Over Time (June 2019 - 2023)
Crosswind Component
Mean Crosswind: 0.06 knots
Crosswind Component (knots)
Hour of Day (UTC)
(f)
Crosswind Components Over Time (July 2019 - 2023)
Crosswind Component
Mean Crosswind: 0.42 knots
Crosswind Component (knots)
Hour of Day (UTC)
(g)
Crosswind Components Over Time (August 2019 - 2023)
Crosswind Component
Mean Crosswind: 0.12 knots
Crosswind Component (knots)
Hour of Day (UTC)
(h)



Figs.13(a-l). Crosswind Component over the time (a) January, (b) February, (c) March, (d) April, (e) May, (f) June, (g) July,(h) August, (i) September, (j) October, (k) November and (l) December

line shows the hourly headwind or tailwind component. It is clear that the headwind or tailwind component fluctuates over the day. Usually, between 6 and 8 UTC, the headwind or tailwind reaches a peak value of around 7 knots while the headwind or tailwind drops to a minimum, approaching values as low as 3 knots around 14 to 16 UTC. This could be implying a clam wind environment during these hours. After this period, the headwind or tailwind component gradually increases but remain relatively close to the mean value.

This diurnal pattern of headwind or tailwind is influenced by the daily heating and cooling cycle occurring sea breeze and land breeze affecting Bandaranaike International Airport. This type of information on wind pattern is crucial for aeronautical meteorology as it helps understand wind behavior that impact flight operations, fuel consumption, and aircraft performance. Airlines can use this kind of data in flight planning to optimize take- off and landing strategies or minimize fuel usage.

The Orientation of the runway at Bandaranaike International Airport is aligned along a 37° (Runway 22) and 217° (Runway 04). According to the direction of headwind or tailwind, they decided the direction of landing or take-off to maximize aircraft performance.

3.5. *Cross wind component*

Fig. 13 displays the Crosswind Components Over Time from January 2019 to 2023 at Bandaranaike International Airport, showing how the crosswind (in knots) varies over the course of a day (UTC).

According to the above figures, the crosswind peaks between 7 and 14 UTC, with a speed of about 6 knots. These points to a time frame in the late morning to early afternoon when crosswinds will be heavier. After 16 UTC, the crosswind drastically decreases, dropping below 2 knots by 17 UTC and staying low the rest of the day. There is also a discernible decrease in the crosswind component between 2 and 4 UTC, with values close to 2 knots, suggesting calmer early morning circumstances.

The crosswind component follows a clear diurnal cycle, with a stronger crosswind during the late morning to early afternoon and weaker crosswinds in the evening and night. Crosswind is critical for aviation safety, as high crosswind values can pose challenges during aircraft take-off and landing, requiring additional pilot expertise or runway adjustments. The peak values observed here could indicate times of the day when extra caution or specific runway use may be necessary to ensure safe operations.

This data is valuable for aeronautical meteorology, as it helps in identifying daily wind trends that impact flight operations, potentially assisting in flight scheduling and runway use planning.

4. Conclusions

The wind analysis conducted for Bandaranaike International Airport from 2019 to 2023 provides valuable insights into the prevailing wind patterns and seasonal variations in wind speed and direction. While the southwest monsoon is more prevalent from May to September, the northeast monsoon is in charge from January to March and again in November and December. Throughout the year, wind speeds typically fall between 3 and 7 knots, with the northeast monsoon months seeing the highest frequencies. The results show that monsoonal changes have a significant impact on wind behavior in the area, with the northeast monsoon bringing comparatively calmer winds from the northeast and the southwest monsoon bringing stronger winds mostly from the southwest.

Seasonal fluctuations have exhibited consistent patterns across the time under analysis, indicating that monsoon cycles significantly influence wind direction and intensity. Airport operations depend heavily on these findings, especially when it comes to flight scheduling, runway usage, and aviation safety procedures. Furthermore, by influencing weather prediction models and enhancing the precision of local forecasts, this approach can support larger meteorological research.

By understanding these wind patterns; Bandaranaike International Airport can better prepare for seasonal shifts, optimize operational planning, and enhance overall safety measures in response to variable wind conditions.

Authors declarations

We, J.S.D.S. Premathilake, Meteorologist, and W.D.T.N. Gunawardhana, Meteorological Observer and Communicator, Department of Meteorology, Sri Lanka, hereby declare that the contents and views expressed in this research paper/article are solely ours and do not necessarily reflect the views of the Department of Meteorology or any other organizations to which we are affiliated.

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Authors' contributions

J.S.D.S. Premathilake: The data analysis, Interpreted the results, and prepared the original manuscript draft (email: darshana.shamil@mail.com)
W.D.T.N. Gunawardhana: Data preparation, Assisted in organizing and restructuring the manuscript, and supported the refinement of the final version (email: send2niluka@gmail.com)

Disclaimer: The contents and views presented in this research article/paper are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

References

Amador, Jorge A., Edward J. Alfaro and Norman E. Poveda, 2006, “Atmospheric Water Vapor Transport to Central America and Its Role in Precipitation." *International Journal of Climatology* **26**, 2, 189-203. https://doi.org.10.1002/joc.1249 .

Atiyat, Omar K., and S. El-Ammari, 2020, “Assessment of Wind Energy Potential for Sustainable Energy Production in Aqaba Special Economic Zone, Jordan”, *Renewable Energy*, **151**, 271-281. https://doi.org.10.1016/j.renene.2020.01.034 .

Bazargan, Massoud, and Peter Kaighobadi. 2017. "Assessing the Impact of Meteorological Conditions on Airport Performance and Delay." *Journal of Air Transport Management*, 62:34-40. https://doi.org.10.1016/j.jairtraman.2017.02.001 .

Chand, Pradeep, *et al*. 2017. "Sea Breeze Dynamics and Its Impact on Airport Operations: A Study at Coastal Airports." *Journal of Atmospheric Sciences”* **74**(2):341-355.

Federal Aviation Administration (FAA). 2019. “*Airport Design and Runway Orientation Guidelines”***.** Washington, D.C.: FAA.

International Civil Aviation Organization (ICAO). 2007. ***“****Manual on Aerodrome Design: Wind Analysis”*. Montreal, Canada: ICAO.

Rojek, Michal, *et al*. 2019. "Wind Direction Variability and Its Influence on Runway Usage: A Case Study of Selected European Airports. “*Transportation Research Procedia***”** 39:195-202.

Smith, Andrew B., *et al*. 2014. "Diurnal Variations in Wind Speed and Direction and Their Impact on Airport Operations." Meteorologica”l Applications 21(2):147-156.

World Meteorological Organization (WMO). 2020. “*Seasonal Weather Variability and Its Impact on Aviation”*. Geneva, Switzerland: WMO.