LJEEST
ISSN 2710-5237
www.srcest.org.ly/jou

المجلة الليبية لعلوم وتكنولوجيا البيئة

Libyan Journal of Ecological & Environmental Sciences and Technology(LJEEST)

DOI: https://doi.org/10.63359/6thv9487

Dynamic Interaction between Wind and Topography during Peak Rainfall over Shahat Area (Al-Jabal Al-Akhdar), Libya: An Applied Study Using Proposed Climatic Index

Mahmood M.M. Soliman

ARTICLE INFO

Vol. 8 No. 1 April, 2026

Pages (123 - 131)

Article history:

Revised form 10 March 2026

Accepted 31 March 2026

Auyther affilitayioon

Department of Geography, Faculty of Arts, University of Tobruk, Libya

mahmood.soliman@tu.edu.ly

Keywords:

wind, topography, rainfall, dynamic interaction, Shahat, Al-Jabal Al-Akhdar, Libya.

ABSTRACT

This study analyzes the interaction between wind and topography and its influence on rainfall in the Shahat area (Al-Jabal Al-Akhdar), northeastern Libya, during the peak rainy season. It develops an applied climatic indicator, the Angular Wind–Rainfall–Topographic Interaction Index (AWRI). The analysis uses meteorological records from the Shahat weather station provided by the Libyan National Center of Meteorology for the climatological period 1981–2010, including rainfall totals, wind speed, and wind direction, alongside topographic slope aspects derived using Digital Elevation Model (DEM). The index integrates rainfall amount, mean wind speed, and the cosine of the deviation angle between wind direction and windward slope orientation, representing the efficiency of orographic uplift. Results show marked interannual variability, with high values when northerly and northwesterly maritime winds align with Al-Jabal Al-Akhdar slopes, enhancing rainfall effectiveness. The findings highlight the importance of incorporating dynamic–topographic factors in interpreting rainfall variability in coastal mountainous environments.

التفاعل الديناميكي بين الرياح والتضاريس خلال ذروة الأمطار في منطقة شحات (الجبل الأخضر)، ليبيا: دراسة تطبيقية باستخدام مؤشر مناخي مقترح

محمود محمد محمود سليمان

تهدف هذه الدراسة إلى تحليل التفاعل بين الرياح والتضاريس وتأثيره في هطول الأمطار بمنطقة شحات (الجبل الأخضر) في شمال شرق ليبيا خلال ذروة الموسم المطري. ولتحقيق ذلك، تم تطوير مؤشر مناخي تطبيقي يُعرف باسم مؤشر التفاعل الزاوي بين الرياح والأمطار والتضاريس (AWRI). اعتمدت الدراسة على السجلات المناخية الصادرة عن محطة شحات للأرصاد الجوية التابعة للمركز الوطني للأرصاد الجوية للفترة المناخية القياسية (1981–2010)، والتي تشمل كميات الأمطار وسرعة الرياح واتجاهها، إضافة إلى اشتقاق اتجاهات الانحدار الطبوغرافي باستخدام نموذج الارتفاع الرقمي (DEM). يدمج المؤشر بين كمية الأمطار ومتوسط سرعة الرياح وجيب تمام زاوية الانحراف بين اتجاه الرياح واتجاه المنحدر المواجه لها، بما يعكس كفاءة الرفع الأوروجرافي. أظهرت النتائج تبايناً سنوياً واضحاً في قيم المؤشر، مع ارتفاع ملحوظ عندما تتوافق الرياح البحرية الشمالية والشمالية الغربية مع منحدرات الجبل الأخضر، مما يعزز فاعلية الهطول المطري. وتبرز النتائج أهمية دمج البعد الديناميكي–الطبوغرافي في تفسير تباين الأمطار في البيئات الجبلية الساحلية.

INTRODUCTION

Rainfall is considered one of the most complex components of the climate system and among the most sensitive to dynamic atmospheric interactions, as it involves an intricate interplay between thermal processes, wind dynamics, and topographic influences. Its formation and spatiotemporal distribution are not solely governed by moisture availability; rather, they are strongly influenced by wind direction and speed, which control water vapor transport as well as ascending and descending air motions, particularly in mountainous regions (Barry & Chorley, 2010). Climatic literature highlights wind as a key factor in explaining rainfall variability, especially through its role in regulating orographic uplift when moist air masses encounter mountainous barriers, thereby enhancing condensation and precipitation on windward slopes while reducing rainfall on leeward sides.

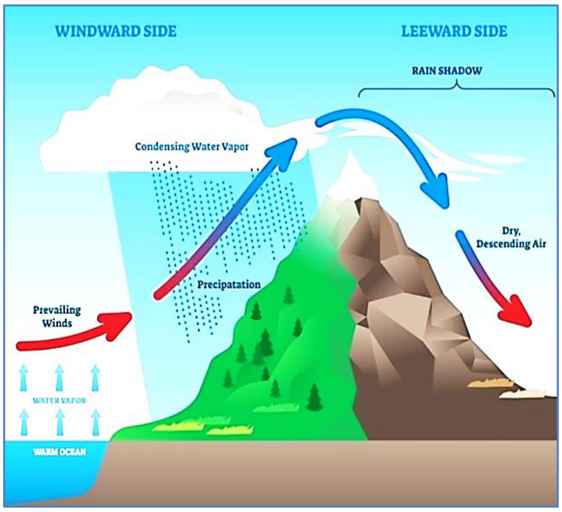

Figure (1): Conceptual diagram illustrating the dynamic interaction between prevailing moist winds and the topography of Al-Jabal Al-Akhdar. It highlights the mechanisms of orographic lifting and cloud formation on the windward slopes versus the rain shadow effect and adiabatic warming on the leeward side.

The efficiency of these processes depends on the interaction between airflow and topography. As moist air ascends windward slopes, sufficient advection time allows for cloud development and precipitation, whereas descending air on the lee side undergoes adiabatic warming, leading to reduced or absent rainfall. This phenomenon, known as the rain shadow effect, explains pronounced spatial contrasts in precipitation within mountainous regions (Lin, 2009). Dynamic Moreover, airflow crossing mountain barriers may generate localized circulation patterns and lee-side convective activity due to vertical pressure gradients and thermal contrasts, contributing to the redistribution of energy and moisture and extending the topographic influence on precipitation patterns beyond immediate windward areas (Smith, 1979; Kochin, 2024).

Amid global climate change, increasing irregularity in precipitation patterns has been widely documented, accompanied by shifts in wind regimes and a growing frequency of extreme weather events (IPCC, 2021). These impacts are particularly evident in climate-sensitive regions such as the Mediterranean Basin and North Africa, where rainfall variability and seasonal irregularity have intensified (Giorgi & Lionello, 2008). Such changes necessitate the development of more precise analytical approaches to better understand the underlying mechanisms of climatic variability at local scales. Despite the abundance of studies addressing rainfall characteristics in the Al-Jabal Al-Akhdar region, most have relied on traditional statistical analyses or general rainfall indices without systematically integrating wind dynamics and topographic variables into a unified analytical framework (Mousa et al., 2012; Al-Hanafi and Nouh, 2012; Ibrahim, 2020; Elgali, 2022; Soliman, 2022; Al-Amrouni et al., 2023). This limitation highlights a clear gap in applied climatological research, particularly in mountainous environments where wind–topography interactions play a decisive role in rainfall formation.

Within this context, rainfall represents a critical component of water resources in Libya, especially in semi-arid regions where it constitutes the primary source of water availability. In eastern Libya, and particularly in the Al-Jabal Al-Akhdar region, rainfall regimes have become increasingly irregular in both magnitude and seasonal distribution. This variability is closely associated with changes in prevailing wind systems, particularly northerly and northwesterly maritime flows originating from the Mediterranean Sea, whose interaction with the region's complex topography plays a fundamental role in cloud formation and precipitation through orographic processes.

Accordingly, this study aims to analyze the dynamic interaction between wind direction, wind speed, and rainfall over the Shahhat area and the broader Al-Jabal Al-Akhdar region using long-term climatic data. It proposes the development of an applied composite index that integrates wind characteristics, topographic variables, and rainfall amounts to evaluate the role of atmospheric dynamics and surface morphology in enhancing or suppressing rainfall efficiency. By linking climatic analysis with local topographic characteristics, the study provides a physically based interpretation of spatial and temporal variability in precipitation.

The scientific significance of this research lies in addressing a gap in applied climatological studies in the Shahhat area through the integration of dynamic atmospheric and topographic factors into a unified analytical framework. Methodologically, the proposed index represents an advancement in local climate analysis tools for coastal mountainous environments, as it combines wind direction, wind speed, rainfall, and slope orientation into a single metric. From an applied perspective, the findings contribute to improved agricultural planning, water resource management, and climate adaptation strategies, thereby enhancing resilience to rainfall variability and climate change impacts in the Al-Jabal Al-Akhdar region.

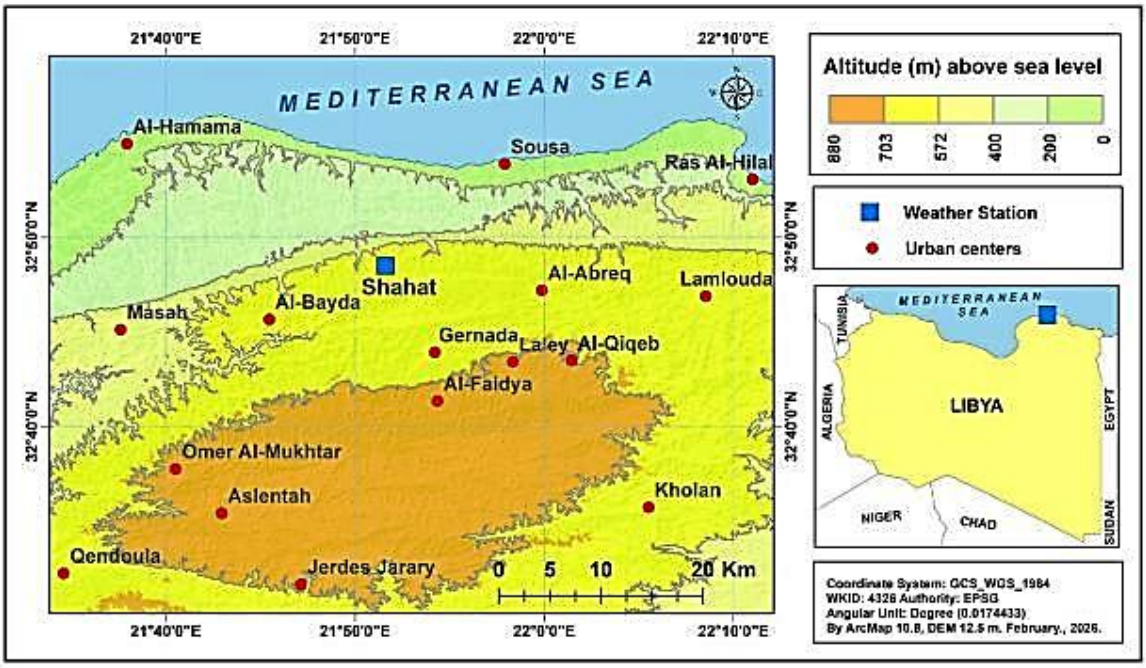

Figure (2): Location and Surface Features of the Study Area

Figure (1) clearly illustrates the elevational gradient across the study area, highlighting the contrast between the north-facing slopes exposed to the Mediterranean Sea and the inland areas located behind the mountain ridges. These topographic characteristics play a pivotal role in steering airflow and modifying wind speed and direction, thereby enhancing orographic uplift mechanisms and promoting rainfall formation, particularly over slopes exposed to moist maritime winds originating from the Mediterranean Sea. Rainfall is largely concentrated during the winter months, whereas relative dryness prevails during the summer season.

The climatic characteristics of the Shahhat meteorological station are marked by moderate maximum temperatures compared to adjacent coastal and lowland areas. Mean monthly maximum temperatures range from approximately 12.5 °C in January to 27.9 °C in July, while minimum temperatures decrease during winter to about 6.3 °C in January and may fall below this level during cold spells (LNMC, 1981–2010). Relative humidity records moderate to high values, ranging between 66.6% in July and 78.5% in January, reflecting the proximity of the region to the Mediterranean Sea and the frequent passage of moist air masses (Soliman, 2020, p. 109). Northerly and northwesterly winds prevail, particularly during the winter season. As a result of the combined influence of these factors, the mean annual rainfall reaches approximately 538 mm, representing the highest average precipitation in Libya. The majority of this rainfall occurs during winter, placing the region within the semi-humid to humid climatic zone according to several climatic classifications (LNMC, 1981–2010; Soliman, 2020, pp. 131–150).

Materials and Methods

Climate and Topographic Data

Climate Data:

This study is based on meteorological records from the Shahhat weather station covering the period 1981–

2010, obtained from the Libyan National Center of Meteorology (LNMC). The dataset comprises monthly rainfall totals, wind speed, and wind direction. This interval corresponds to the internationally adopted standard climatological normal period recommended by the World Meteorological Organization (WMO), ensuring the statistical representativeness and reliability of the climatic averages used in the analysis. Following 2010, the continuity and completeness of observational records at Shahhat station—similar to many meteorological stations across Libya—became increasingly limited, leading to discontinuities that constrain the use of more recent data for robust climatological assessment. Consequently, the selected period constitutes the most consistent and uninterrupted time series available, providing a sound empirical foundation for examining the dynamic interaction between wind, topography, and rainfall in the study area. Wind directions were processed using a circular angular system (0–360°), wind speeds were converted from knots to meters per second (m/s), and rainfall amounts were derived from monthly precipitation totals (mm), with January emphasized as representative of peak winter rainfall conditions.

Figure (2) illustrates the directional and dynamic characteristics of wind during January at Shahhat station, alongside rainfall amounts. The figure indicates a dominance of northerly and northwesterly winds, topographically aligned with the north to northwest-facing slopes of Al-Jabal Al-Akhdar exposed to the Mediterranean Sea. Wind speeds associated with these directions fall within a range conducive to effective orographic uplift. Consequently, the figure emphasizes the physical foundation of the proposed index, which is based on integrating wind direction with local topography to assess its influence on precipitation patterns.

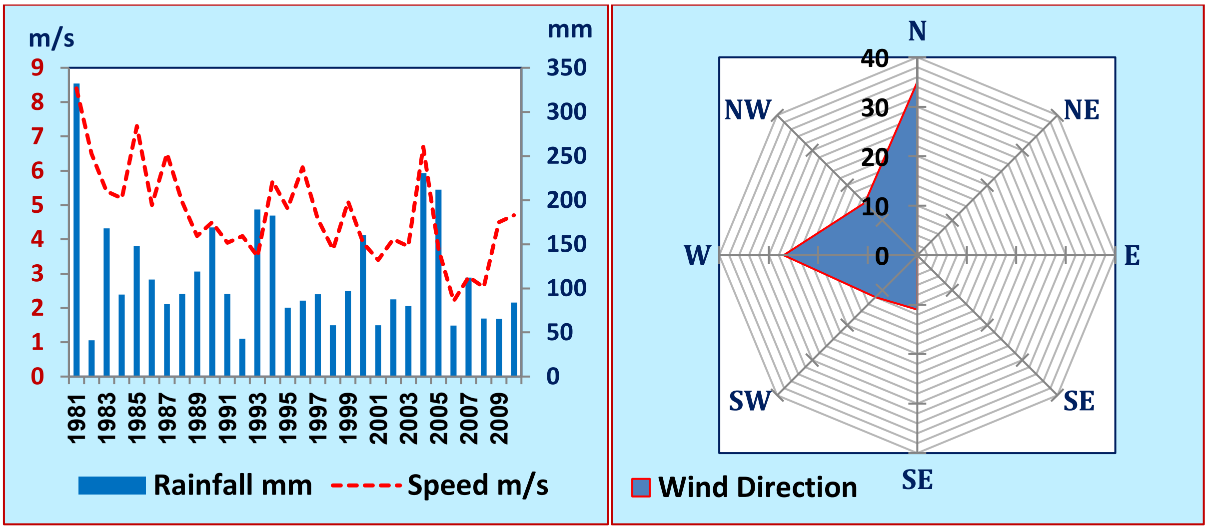

Figure (3): Prevailing Wind Directions, Wind Speeds, and Precipitation Amounts at Shahat Station during January (1981–2010)

Source: Based on wind speed and precipitation data from Shahat Station (1981–2010).

Topographic Data:

Topographic data concerning slope aspects were extracted from a Digital Elevation Model (DEM) with a spatial resolution of 12.5 m, using ArcMap GIS within a Geographic Information System (GIS) environment, specifically employing the Aspect tool from the 3D Analyst toolbox. This tool is used to determine the slope orientation according to a circular angular system (0–360°). The predominant windward slope directions were identified for the Shahhat station and its surrounding areas, particularly the north and northwest-facing slopes, which are most exposed to moist winds affecting rainfall amounts Figure (3).

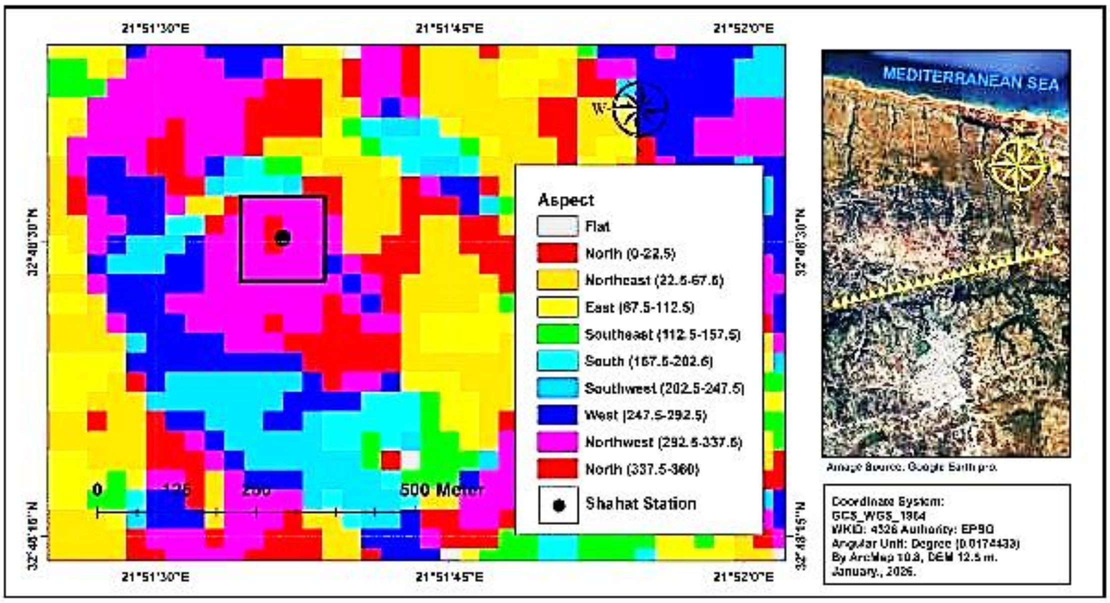

Figure (4): Map Showing Slope Aspect of the Study Area

Proposed Index:

This study developed an interactive angular wind–rainfall index, denoted as AWRI (Angular Wind–Rainfall Interaction). The index integrates the angular deviation of the wind relative to the slopes (A), the effect of wind speed (W), and the rainfall amount (R) to reflect the overall interaction (I) between wind and precipitation over mountainous slopes. The proposed index is based on a physical climatological hypothesis which states that the influence of wind on rainfall efficiency is not determined by wind speed alone, but also by wind direction and its angle of incidence relative to the primary slopes. Mathematically, the index is expressed by the following equation:

$$AWRI = \frac{P \times V \times \cos(\theta)}{\overline{P}}$$

Where:

AWRI = Angular Wind–Rainfall Interaction Index

P = Rainfall amount (mm) during the wettest month of the observation period

V = Wind speed (m/s) during the wettest month of the observation period

Cos(θ) = Cosine of the deviation angle between the prevailing wind direction and the orientation of the windward mountain slope

$\overline{\mathbf{P}}$ = Long-term mean rainfall (mm) for the wettest month over the observation period

High AWRI values indicate the coincidence of higher rainfall with strong winds and a wind direction favorable for orographic uplift, reflecting the effectiveness of wind dynamics in enhancing orographic precipitation. Conversely, low AWRI values denote a weaker influence of wind on rainfall. The following table defines the four thresholds of the index.

Table (1): AWRI Index Thresholds

Category	AWRI Value	Interpretation
Low	≤ 1.5	Weak influence of wind on rainfall
Moderate	1.6 < - ≤ 3.5	Moderate interaction between wind and topography
High	3.6 < - ≤ 5.0	High effectiveness of wind in enhancing rainfall
Very High	> 5.0	Very strong dynamic interaction

Source: Prepared by the author based on AWRI calculations.

The AWRI is designed as a relative, unbounded interaction index rather than a standardized or normalized index confined to a fixed numerical range (e.g., 0–1 or 0–10). It produces continuous values that vary according to the combined intensity of rainfall, wind speed, and the directional relationship between airflow and topographic orientation.

Determination of the Deviation Angle between Wind Direction and Slopes: After processing the wind and rainfall data, the deviation angle (θ) between the prevailing wind direction and the orientation of the windward slope was determined, as it constitutes a key component in calculating the AWRI index. The slope orientation values obtained from the Aspect tool represent the direction faced by the slope, assumed to be the orientation most affected by the incoming prevailing winds.

Subsequently, the deviation angle (θ) was calculated as the absolute angular difference between the prevailing wind direction, extracted from Shahhat station data, and the orientation of the windward slope derived from the Aspect map. This difference was expressed within the range of 0–180° along the directional domain. In simple terms, the deviation angle (θ) was computed as:

$$\theta = W_d - S_d$$

where W_d denotes the wind direction and S_d denotes the slope orientation. This angle serves as a direct indicator of the alignment between wind direction and local topography. Small deviation angles indicate that winds approach nearly perpendicular to the slope, enhancing the efficiency of orographic lifting, whereas large angles signify a weaker orographic effect.

Extraction of Cosine Values (cos θ):
The deviation angles (θ) calculated between the prevailing wind direction and the orientation of the windward slope were used to derive the cosine correction factor (cos θ). This factor serves as a correction coefficient reflecting the actual efficiency of wind in producing orographic uplift and enhancing precipitation over mountain slopes. The cosine values were computed using Microsoft Excel by first converting the angles from degrees to radians using the RADIANS function, followed by applying the COS function to obtain the cosine values for each year of the observation period.

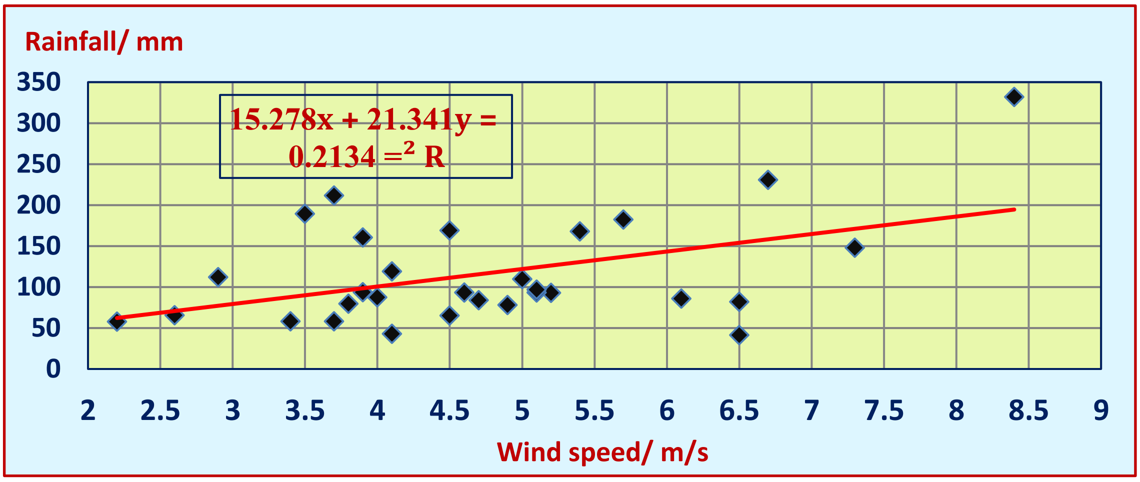

Figure (4): Relationship between wind speed gradient and rainfall amount during January at Shahhat station for the period 1981–2010.

Figure (5) illustrates the linear regression relationship between mean wind speed and rainfall amounts during January at Shahhat station over the period 1981–2010, and is employed as a complementary statistical approach to explore the interaction among the index variables. The results indicate a weak to moderate positive association between the two parameters, as evidenced by the positive slope of the regression equation *(y = 21.341x + 15.278)*, implying that higher wind speeds are generally accompanied by a relative increase in rainfall during the peak rainy season. However, the coefficient of determination (R^2 = 0.2134) indicates that wind speed explains only about 21% of the variability in precipitation, reflecting the limited explanatory power of the direct linear relationship when wind speed is considered in isolation from other influencing factors. This finding confirms that the impact of wind on precipitation does not depend solely on its intensity, but is more strongly

influenced by its direction and degree of alignment with the mountainous slopes. Accordingly, this result highlights the importance of the Angular Wind–Topography–Rainfall Interaction Index (AWRI), which goes beyond univariate analysis by integrating wind speed with the deviation angle (θ) and the correction factor *(cos θ)*. This approach allows for a more accurate and realistic representation of the actual efficiency of orographic uplift in explaining rainfall variability over the slopes of Al-Jabal Al-Akhdar.

Discussion of Results

Table (2) presents the annual AWRI variables for January at Shahhat station, integrating wind parameters (speed and direction) with rainfall amounts (mm), along with the calculated deviation angle (θ) between the prevailing wind direction and the orientation of the windward slope, the corresponding cosine factor (cos θ), and the AWRI values for each year.

Table (2): Components of the AWRI Index and Its Results for January at Shahat Station

Years	Wind Variables January		θ	cos (θ)	P mm January	**AWRI Results**	
	Speed m/s	Direction°				Value	Class.
1981	8.4	280	30	0.8776	332.1	**11.1**	**Very High**
1982	6.5	190	120	0.6479	41.2	**1.5**	**Low**
1983	5.4	350	40	0.8004	168.0	**6.2**	**Very High**
1984	5.2	290	20	0.9421	92.8	**3.9**	**High**
1985	7.3	350	40	0.8004	148.1	**7.4**	**Very High**
1986	5.0	350	40	0.8004	109.8	**3.8**	**High**
1987	6.5	350	40	0.8004	81.9	**3.7**	**High**
1988	5.1	230	80	0.5530	93.5	**2.3**	**Moderate**
1989	4.1	350	40	0.8004	119.0	**3.4**	**Moderate**
1990	4.5	350	40	0.8004	168.9	**5.2**	**Very High**
1991	3.9	330	20	0.9421	93.7	**3.0**	**Moderate**
1992	4.1	350	40	0.8004	42.8	**1.2**	**Low**
1993	3.5	350	40	0.8004	189.3	**4.6**	**High**
1994	5.7	170	140	0.8004	182.5	**7.2**	**Very High**
1995	4.9	260	50	0.7207	78.0	**2.4**	**Moderate**
1996	6.1	260	50	0.7207	86.0	**3.3**	**Moderate**
1997	4.6	170	140	0.8004	93.2	**3.0**	**Moderate**
1998	3.7	170	140	0.8004	58.3	**1.5**	**Low**
1999	5.1	260	50	0.7207	97.0	**3.1**	**Moderate**
2000	3.9	260	50	0.7207	160.4	**3.9**	**High**
2001	3.4	170	140	0.8004	58.0	**1.4**	**Low**
2002	4.0	290	20	0.9421	87.4	**2.8**	**Moderate**
2003	3.8	260	50	0.7207	79.8	**1.9**	**Moderate**
2004	6.7	260	50	0.7207	230.7	**9.6**	**Very High**
2005	3.7	260	50	0.7207	211.8	**4.9**	**High**
2006	2.2	260	50	0.7207	57.7	**0.8**	**Low**
2007	2.9	290	20	0.9421	112.0	**2.6**	**Moderate**
2008	2.6	350	40	0.8004	65.6	**1.2**	**Low**
2009	4.5	170	140	0.8004	65.3	**2.0**	**Moderate**
2010	4.7	350	40	0.8004	83.9	**2.7**	**Moderate**
Average	**4.7**	**277**	**60**	**0.7900**	**116.3**	**3.72**	**High**

*The mean slope orientation of the area is **310° (northwest)**, and the long-term average precipitation in January over the observation period is **$\overline{P}$ = 116.3 mm/ January**.

Through Table (2) and Figure (5), the application of the AWRI index reveals a clear variability in the interaction between wind and topography and its effect on enhancing precipitation during January, reflecting the dynamic nature of the winter climate system in the Shahhat area. The AWRI values are distributed across the four established categories, indicating interannual differences in the efficiency of wind-induced orographic uplift. The overall mean AWRI value is 3.72, which falls within the high-impact threshold.

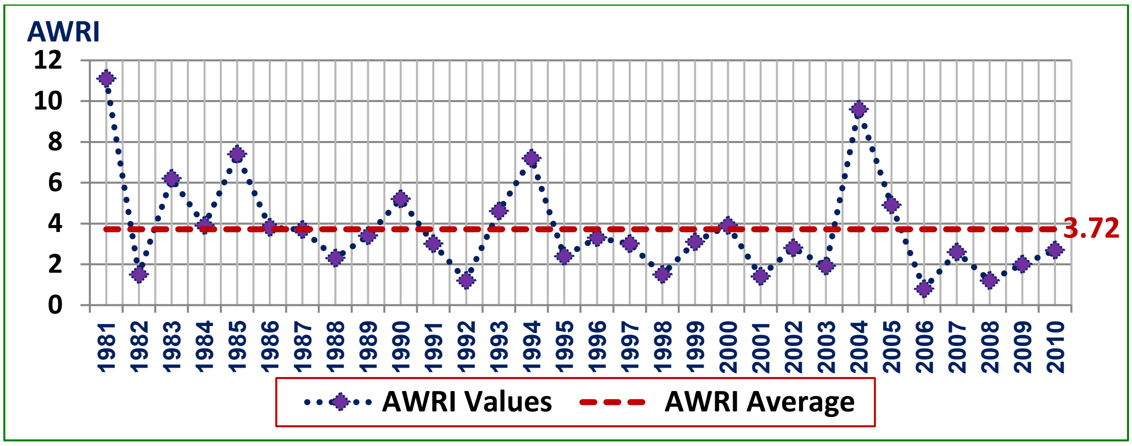

Figure (6): Graphical representation of the results of applying the AWRI index at Shahat Station for the period 1981–2010.

Years with AWRI ≤ 1.5 (Low category), representing 6 years or 20% of the observation period, correspond to conditions where wind had a weak influence on rainfall. This can be attributed to one or both of the following factors: low effective wind speeds or misalignment between wind direction and windward slopes, which reduces the vertical component of wind and limits orographic lifting, even in the presence of moderate rainfall amounts.

The Moderate category (1.6 < AWRI ≤ 3.5), which is the most frequent, includes 11 years or 37% of the observation period. This category reflects a moderate interaction between wind and topography, where wind speeds and directions are partially favorable for orographic uplift. These values represent the prevailing winter pattern in Shahhat, characterized by a noticeable but not fully decisive topographic influence, indicating that precipitation is also governed by additional dynamic factors such as the intensity of Mediterranean cyclones and the upper-atmosphere structure.

The High interaction category (3.6 < AWRI ≤ 5.0) occurs in 6 years (20% of the observation period), indicating a significant effectiveness of wind in enhancing rainfall, where wind speeds are adequate and directionally aligned with the north and northwest-facing slopes of Al-Jabal Al-Akhdar. These values confirm the pivotal role of topography in amplifying the rainfall response to winter weather systems, particularly when moist maritime winds coincide with windward slopes.

Finally, Very High values (AWRI > 5.0) occur in 7 years (23% of the observation period), representing extremely strong dynamic interactions. In these years, conditions are exceptional, with a combination of high rainfall amounts, effective wind speeds, and small deviation angles, resulting in maximum efficiency of orographic uplift.

Conclusions and Recommendations

The application of the Angular Wind–Topography–Rainfall Interaction Index (AWRI) revealed a clear variability in the effectiveness of wind in enhancing precipitation at Shahhat station, with values ranging from Low to Very High. High AWRI values were associated with the alignment of prevailing winds with the windward slopes of Al-Jabal Al-Akhdar, combined with sufficiently strong wind speeds to maximize the vertical wind component. This alignment enhanced the efficiency of orographic uplift, resulting in an amplified precipitation response. Conversely, some years exhibited low AWRI values despite occurring during the peak of the rainy season, reflecting the limited influence of wind when directional alignment or wind speed was insufficient. These findings confirm that winter rainfall variability is not solely controlled by moisture availability, but is fundamentally influenced by the dynamic interaction between wind and topography.

The study recommends reusing the AWRI index as an analytical tool in applied climatological studies in coastal mountainous regions, to test its ability to explain rainfall variability at other stations within the Jabal al-Akhdar or Jabal al-Gharbi, and even in coastal mountainous environments outside Libya. Such applications would allow for verification of its methodological robustness. Furthermore, the study emphasizes the necessity of maintaining and supporting meteorological observation networks to provide updated data, which are crucial for the development of composite climatic indices and for improving the understanding of orographic precipitation mechanisms.

REFERENCES:

Agustin, R. A., Ekawita, R., Supiyati, S., & Alfando, A. (2025). The influence of wind direction and speed on rainfall in Bengkulu City (2019–2023) based on the Schmidt-Fergusson and Wind Rose models. Jurnal Pendidikan Fisika dan Teknologi, 11(1), 232–239. https://doi.org/10.29303/jpft.v11i1.8749

Al-Hanafi, Mohamed Ghazi & Nouh, Saad Idris (2012). The equivalent mean of rainfall and quantitative estimation of precipitation over the Jabal al-Akhdar Basin – Libya (in Arabic). In: Proceedings of the First International Conference on Water Resources in Jabal al-Akhdar, Faculty of Natural Resources and Environmental Sciences, Omar Al-Mukhtar University, 5–7 June 2012. https://www.idosi.org/larcji/3(S)12/5.pdf

Barry, R. G., & Chorley, R. J. (2010). Atmosphere, Weather and Climate (9th ed.). Routledge. https://doi.org/10.4324/9780203871027

Elgali, Jumma A. (2022). Trends in rainfall amounts in northeastern Libya during the period 1961–2010 (in Arabic). Al-Mukhtar Journal of Humanities, Issue 38, 2022. https://doi.org/10.54172/8xb88p28

ESRI. (2019). ArcMap GIS Desktop. https://www.esri.com

Giorgi, F., & Lionello, P. (2008). Climate change projections for the Mediterranean region. Global and Planetary Change, 63(2–3), 90–104. https://doi.org/10.1016/j.gloplacha.2007.09.005

IPCC. (2021). Climate Change 2021: The Physical Science Basis. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/

Kochin, A. V. (2024). The influence of orography and the direction of prevailing winds on precipitation distributions. arXiv. https://doi.org/10.48550/arXiv.2403.06193

Libyan National Meteorological Center (LNMC). (2011). Tripoli, Libya: Climate and Climate Change Department, LNMC. (Unpublished Climate Data).

Lin, Y.-L. (2009). Dynamics of orographic precipitation. Cambridge University Press. https://www.cambridge.org/core/books/mesoscale-dynamics/dynamics-of-orographic-precipitation/E647B2CAC4064BF44207CA4C4A7EF975

Mousa, Abdelhafiz Abdelrahman; Al-Naimi, Ali Shaker; Al-Zentani, Abu Ajila Saad; Khalifa, Mohamed Ali (2012). Trends in rainfall amounts and their impact on water resources in the Jabal al-Akhdar region – Libya (in Arabic). International Journal of Environment and Water. https://www.researchgate.net/publication/358270738_atjahat_altghyr_fy_kmyat_alamtar_wathrha_ly_almward_almayyt_fy_aqlym_aljbl_alakhdr_-_lybya

Smith, R. B. (1979). The influence of mountains on the atmosphere. Advances in Geophysics, 21, 87–230. https://doi.org/10.1016/S0065-2687(08)60262-9

Soliman, M. M. M. (2020). Trend analysis of temperature and precipitation data in the northern part of Libya (1971–2010) (Doctoral dissertation, Karabük University, Turkey). YÖK National Thesis Center. https://tez.yok.gov.tr/UlusalTezMerkezi/

Soliman, M. M. M. (2022). Analysis of evaporation trends in the Al-Jabal Al-Akhdar and Benghazi Plain regions – Libya 1966–2010 (In Arabic). University of Sirte Journal of Humanities, 12(1). https://doi.org/10.37375/sujh.v12i1.55