

Article

Wind and Humidity Nexus over Uganda in the Context of Past and Future Climate Volatility

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Abstract: Wind and humidity are two very vital climate variables that have received little attention by researchers regarding Uganda. This study sought to close this knowledge gap by exposing the dynamics and relationship of windspeed and humidity in Uganda from 1980 to 2023 as well as predicting the future trends from 2025 to 2040. Using high-resolution gridded windspeed and relative humidity (RH) data for the past and seven downscaled and bias-adjusted global climate models within the coupled model intercomparison project phase 6 framework under two shared socioeconomic pathways (SSPs), SPP245 and SSP585, we employed variability, trend, and correlational analyses to expose the wind–humidity nexus at a monthly scale. The results showed a domination of winds of the calm to gentle breeze category across the country, with a maximum magnitude of 6 knots centered over eastern Lake Victoria and eastern Uganda over the historical period. RH was characterized by high to very high magnitudes, except the northern tips of the country, where RH was low for the historical period. Seasonally, both windspeed and RH demonstrated modest variations, with June–July–August (JJA) and September–October–November (SON) having the highest magnitudes, respectively. Similarly, both variables are forecasted to have significant distribution and magnitude changes. For example, windspeeds will be dominated by decreasing trends, while RH will be dominated by increasing trends. Finally, the correlation analysis revealed a strong negative correlation between windspeeds and RH for both the past and future periods, except for the March–April–May (MAM) and September–October–November (SON) seasons, where positive correlations were observed. These findings have practical applications in agriculture, hydrology, thermal comfort, disaster management, and forecasting, especially in the northern, eastern, and Lake Victoria basin regions. The study recommends further finer-scale research at various atmospheric levels and for prolonged future periods and scenarios.

Keywords: wind; humidity; spatiotemporal; trends; relationship; future; CMIP6 models; Uganda



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1. Introduction

Atmospheric circulations such as wind are the fundamental determinants and drivers of key climate variables such as humidity, precipitation, and temperature. Both windspeed and humidity regulate atmospheric processes such as horizontal and vertical moisture [1]

and heat transportation [2,3] in the atmosphere, thus being crucial in cloud development, rainfall formation [4], and heat distribution. The dynamics of wind and humidity are complex and interconnected, playing crucial roles in shaping our climate and weather patterns [5,6]. For example, while humidity affects the availability of surface moisture, energy budget, human thermal comfort, and environmental systems [7,8], wind plays an important part in the distribution of humidity across the globe [9]. Thus, wind is key in shaping the climate and weather patterns, and its impact on the humidity distribution is complicated. Various studies have also pointed to wind's role in (i) the transport and distribution of pollutants over long distances [10], (ii) promoting the airborne propagation of virus particles [11], and (iii) pest distribution.

Winds are among the most important factors influencing Uganda's weather. Some examples include the monsoonal winds originating from the sub-tropical anticyclones over the Indian and Atlantic Oceans and moist westerly breezes from the Congo Basin [12–14]. Surface trade winds carry heat and moisture from evaporation and sensible heating, resulting in enhanced convection, cloudiness, and precipitation [15], hence having a considerable influence on weather conditions [16–18]. Ayanlade et al. [15] indicated that seasonal fluctuations in the location of humidity and wind significantly affect rainfall distribution, resulting in wet and dry seasons. At a regional scale and externally, Ogwang et al. [19] and Ngoma et al. [20] demonstrated the role circulation anomalies over the Indian and Atlantic Oceans play in the observed rainfall extremes over Uganda during the September to November season.

In Uganda, much attention has been paid to other weather variables, like precipitation [21,22], temperature [23], and, recently, evapotranspiration [24,25]. Less attention has thus been paid to winds, yet they play a great role in the distributions of temperature, precipitation, and evapotranspiration. For example, only a handful of studies, such as Pallabazzer and Sebbit [26] and Mustafa [27], can be cited for wind variability either at a temporal or spatial scale but not both. Moreover, these studies were conducted at very low resolutions. Air humidity, on the other hand, has only been indirectly explored by Yang et al. [28] and Kabano and Lindley [8] for a few selected locations in Uganda and at short temporal scales, with Kabano and Lindley [8] exclaiming the limitedness of humidity studies in the region. It is also worth mentioning that no study has yet explored the future dynamics of windspeeds and air humidity over Uganda, let alone their relationship. Given their strong and proven roles in the hydrological, agricultural [29,30], health [8,28], disaster [31], and energy [32,33] sectors of Uganda, as well as weather and climate prediction services [22,34], it was prudent to explore the nexus between wind and humidity, and their respective dynamics over Uganda, for both historical and future periods. Thus, the objectives of this study were to (i) explore the spatiotemporal distributions of windspeed and air humidity over Uganda for the periods 1980–2023 and 2025–2040 and (ii) determine the relationship between windspeeds and air humidity over Uganda for both the historical and future periods at high temporal and spatial resolutions.

2. Study Area, Data, and Methods

2.1. Description of Study Area

This study was carried out over Uganda, a developing country in East Africa (Figure 1). Uganda occupies roughly 241,548 km² and accounts for 0.8% of Africa's total geographical area. Geographically, the country is located between 1°30' S–4° N latitude and 29°30' E–34° E longitude, therefore crossed by the equator [35]. The climate in Uganda is characterized by wet and dry seasons. Rainfall ranges from 500 mm to 2000 mm from March to May and October to November, with temperatures ranging from 20 °C to 25 °C from November to March [36].

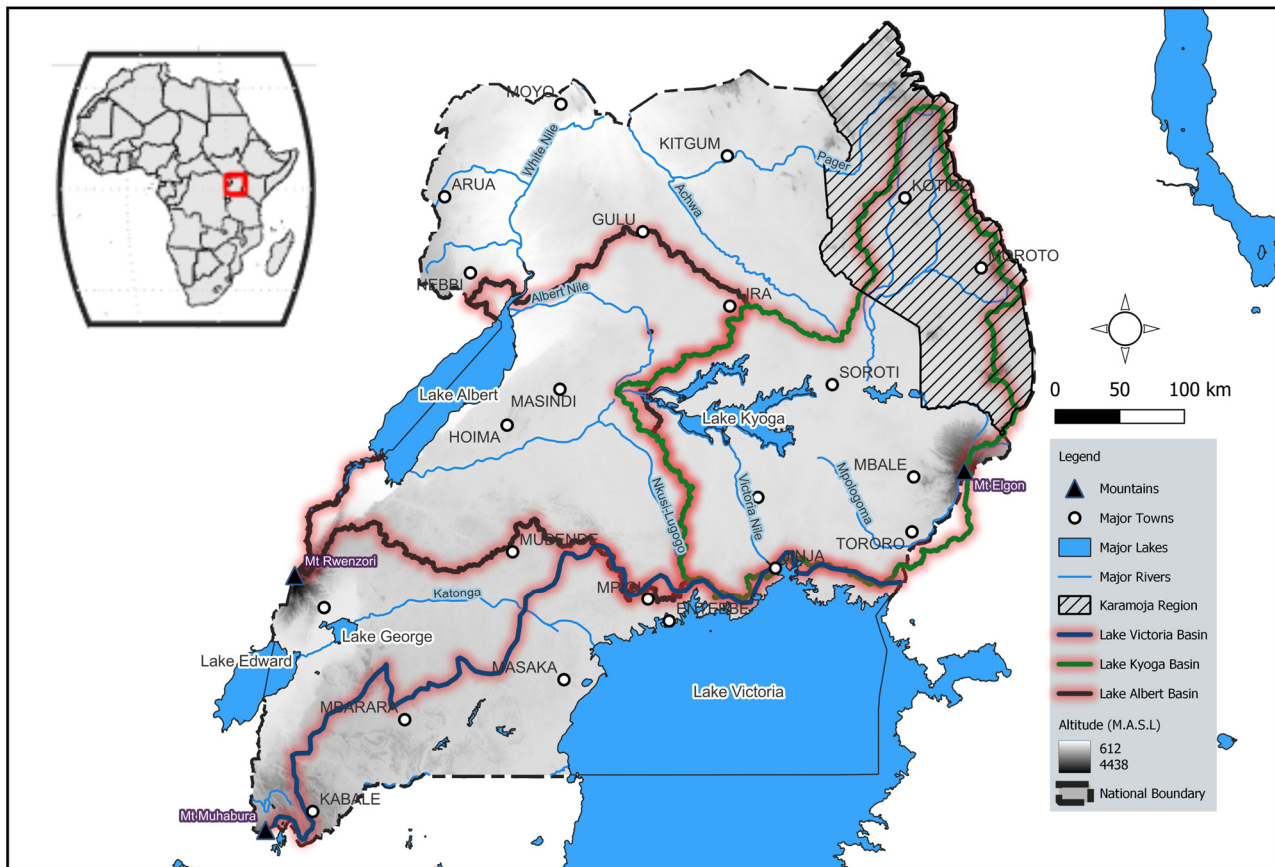


Figure 1. Location of Uganda on the African continent (red square), its topo-hydrography, and major towns and regions.

2.2. Data and Methods

2.2.1. Data Sources and Pre-Processing

Historical Wind and Humidity Data

Gridded windspeed, vapor pressure, and vapor pressure deficit data for the period 1980–2023 were sourced from TerraClimate [37].

TerraClimate database is a high-resolution (~ 4 km) global climate dataset that provides monthly climate and climatic water balance information for terrestrial surfaces (from 1958 to present). TerraClimate can be accessed at University of Idaho Climate Research Group [37]. Vapor pressure deficit and vapor pressure data were used to compute relative humidity (RH) using the Magnus–Tetens equations [38]. The data were acquired in Network Common Data Format (NetCDF) file format for the Uganda country bounds spanning 4.2 N–1.5 S and 29 E–36 E and pre-processed in MATLAB R2019a software [39]. We then extracted and aggregated wind and humidity data into the four major seasons in Uganda. December–January–February (DJF) and June–July–August (JJA) represent the two dry seasons, and March–April–May (MAM) and September–October–November (SON) represent the two wet seasons. TerraClimate data were chosen for their high resolution, consistency, and ability to reproduce seasonal climatology over most stations in Uganda in comparison with data observed in situ [25].

Future Windspeed and Humidity Data

Downscaled relative humidity and windspeed data for the period 2025–2040 from seven coupled model inter-comparison project phase six (CMIP6) models (Table 1) were considered in this study. The CMIP6 models are driven by the new shared socioeco-

nomic pathways (SSPs). In this study, two SSPs, i.e., SSP245 and SSP585, were considered because SSP245 is considered a realistic baseline scenario and serves as a reference case, while SSP585 represents an upper-bound scenario that helps in risk assessments. The adopted NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) [40] were downscaled using the Bias Correction and Statistical Downscaling (BCSD) method [41–43] from parent coarse resolutions ranging from $1^\circ \times 1^\circ$ to $2.5^\circ \times 2.5^\circ$ to a finer $0.25^\circ \times 0.25^\circ$. In addition to greenhouse gases, aerosols, and other climate forcings used in CMIP5, CMIP6 represents a substantial refinement over its predecessor, including more modeling groups and different socioeconomic factors in the emission scenarios [44]. The scenarios used in CMIP6 combine SSPs and target radiative forcing levels at the end of the 21st century. Thus, SSP126, SSP245, SSP370, and SSP585 indicate the socioeconomic development together with CO₂ emissions from the lowest to the highest levels [45], representing a continuum from more aggressive mitigation strategies targeting a sustainable path of lower CO₂ emissions (SSP1) to a fossil-fueled development with higher emissions (SSP5) [44]. A detailed description of the CMIP6 framework and SSP design can be found in Neill et al. [46] and Meinshausen et al. [47].

The adopted CMIP6 models are summarized in Table 1. The multi-model ensemble (MME) of seven CMIP6 models was utilized. The use of MME reduces the uncertainties and made climate projection more reliable [48]. The underlying assumptions of the multi-model ensemble mean practice is that all models are reasonably independent, equally plausible, and distributed around the reality [49]. MME means for individual variables (windspeed and relative humidity) from the seven Global Circulation Models (GCMs) for each scenario were therefore computed and considered.

Table 1. Shows the adopted GCMs and summary information.

Model	Downscaled Resolution	Variables	Scenario	Reference
ACCESS-ESM1-5	25 × 25 km	Windspeed and RH	SSP245 and SSP585	[50]
CanESM5	25 × 25 km	Windspeed and RH	SSP245 and SSP585	[51]
HadGEM3-GC31-MM	25 × 25 km	Windspeed and RH	SSP245 and SSP585	[52]
GFDL-CM4-grl	25 × 25 km	Windspeed and RH	SSP245 and SSP585	[53]
GFDL-ESM4	25 × 25 km	Windspeed and RH	SSP245 and SSP585	[54]
IPSL-CM6A-LR	25 × 25 km	Windspeed and RH	SSP245 and SSP585	[55]
UKESM1-0-LL	25 × 25 km	Windspeed and RH	SSP245 and SSP585	[56]

2.2.2. Spatiotemporal Variability and Trend Analysis

The spatiotemporal variability of historical and future windspeed and RH was computed as a variance at given grid cell over the study period. The variance, also given as the square of standard deviation of each of the climate variables, was then expressed as contours using the contour function embedded in the CDT Toolbox version 1 [57] in MATLAB [39]. Variability analysis was chosen as it helps to reveal the instability of a given climate variable in space and time.

The long-term trends in both historical and future windspeeds and RH and their associated magnitudes were determined using Mann–Kendall trend test [57,58] and Sen’s slope estimator, respectively. The test is generally preferred over others, especially in hydrometeorological studies, for its non-parametric nature and less sensitivity to outliers relative to other parametric methods [59,60], among other strengths. Drápela and Drápelová [61] and Solaimani and Bararkhanpour Ahmadi [62] provide a detailed outlook of computation procedure for Mann–Kendall and Sen’s slope estimates. The test was performed using the trend test with Kendall-option function embedded in the CDT Toolbox [57] in MATLAB [39].

In this study, the existence of trends or not in both historical and future windspeed and RH data was tested at 5% level of significance.

2.2.3. Spatiotemporal Correlation Analysis

The correlation coefficient metric was considered sufficient for the determination of wind–humidity nexus over Uganda for both the historical and future periods. In this study, we employed the Pearson correlation coefficient for its robustness in quantifying degrees of linear correlation in atmospheric variables in space [63] using the Corr function in MATLAB [39]. Given the 3D nature of both wind and humidity data, we looped the ordinary Pearson correlation coefficient embedded in the Corr function over the corresponding grid cells in windspeed and RH data represented by Lat, Lon coordinates. This approach is robust as it ensures grid independence and seamless computation/performance. The significance of the association was tested at $\alpha = 0.05$ level of significance.

All the analyses were conducted in MATLAB software [39] using both live scripts and associated toolboxes.

Figure 2 shows the research design and flow process adopted for this study.

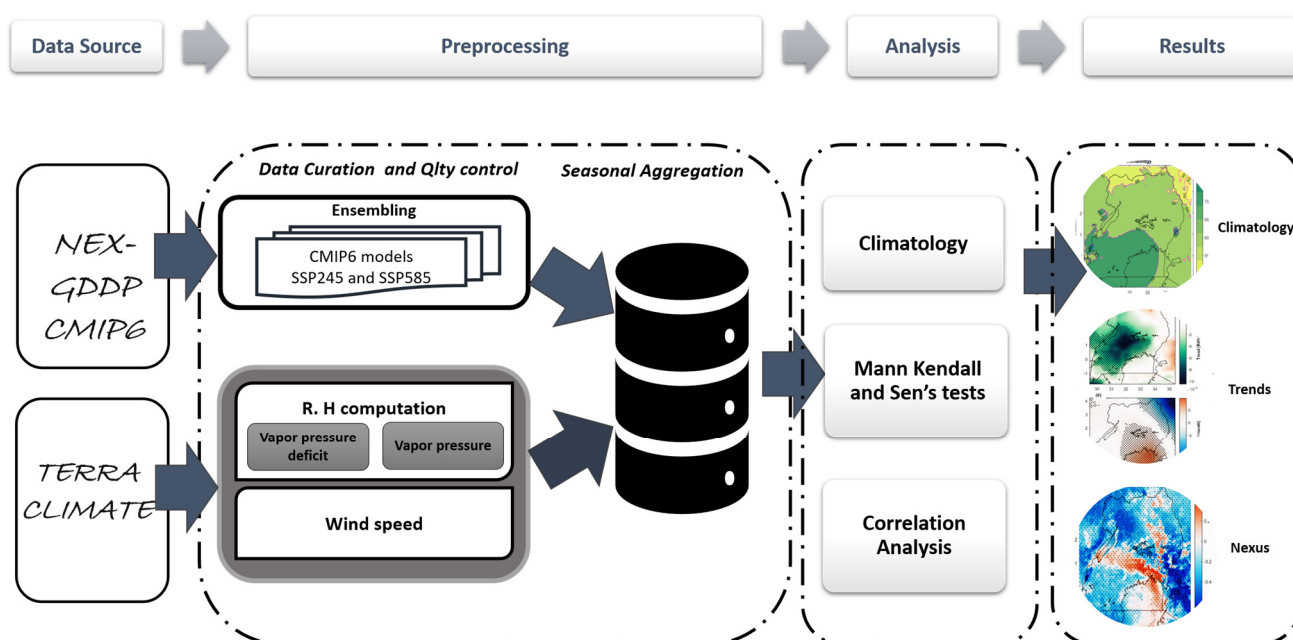


Figure 2. Graphical overview of the methodology for the study.

3. Results

3.1. Historical and Future Climatology of Windspeed over Uganda

Uganda's windspeed climatology for the period 1980 to 2023 (Figure 3a) can be summarized in three homogenous classes represented by colors: cyan, azure, and blue. Class 1 (blue) is associated with wind forces of a magnitude of 5 knots and above, centered over the central, southern, eastern, and northern parts of Lake Victoria, with a northward extension towards and beyond Lake Kyoga. Class 2 (azure blue) is associated with magnitudes in the range of 4–5 knots, encompassing the largest part of the country and spanning the western–central, northern, and northeastern regions. Class 3 (cyan) takes a similar share as class 1, with monthly magnitudes of <4 knots, and spans the southwestern, western, and northwestern parts of the country. The three classes occupy the country 30%, 40%, and 30%, respectively. There are no significant variations in windspeeds spatially. However, over time, strong variability is observed in northeastern Uganda, the northern Lake Victoria shores, and over the highland areas.

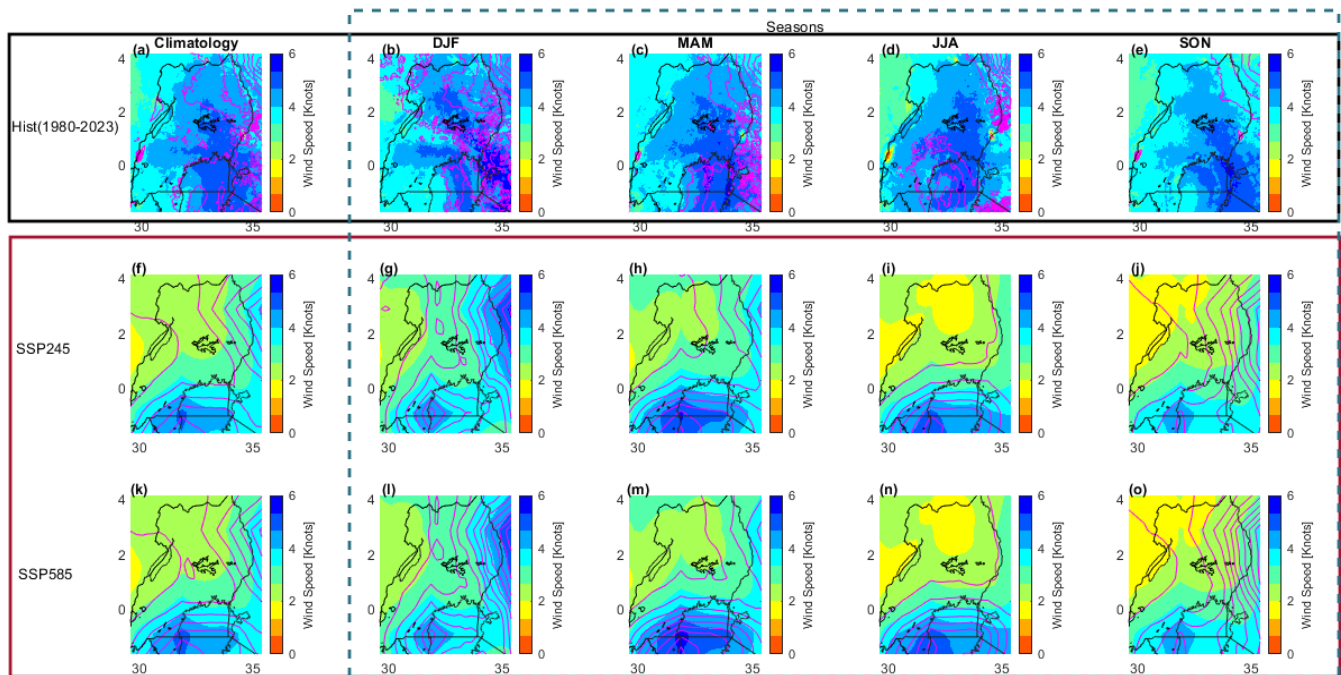


Figure 3. Climatology (a,f,k) and seasonality (b–e,g–j,l–o) of monthly average windspeed over Uganda for both the historical (a–e) and future (f–o) periods. Magenta contours indicate variability, whose intensity is depicted by contour compactness. Note that contours have slight changes in color appearance due to different color background upon which they are overlaid. This however does not change the meaning and interpretation.

At the seasonal scale (Figure 3b–e), the strongest windspeeds across the country are observed during the JJA season, with over 50% of the country experiencing winds of magnitude 5 knots and above. This is observed in areas within central and eastern Uganda, those surrounding Lake Kyoga, and over Lake Victoria. The largest spatial windspeed range of <1 to 6 knots is also observed during this season between the mountains of Rwenzori in the southwest, Elgon in the east, and low-lying areas within the Lake Victoria Basin (LVB) and Lake Kyoga Basin (LKB) of Uganda. The season with the lowest windspeed distribution over most parts of the country is SON, while the highest temporal variability is observed during the DJF season over the north, central, east, and southeastern parts of the country.

The future, on the other hand, based on both SSP245 and SSP585, will be dominated by windspeeds of slightly lower magnitude (Figure 3f,k). For example, the lowest windspeeds in the range of 2–2.5 knots are forecasted over the north and the Lakes Kyoga and Albert Basins, covering 50% of Uganda. This will be followed by a 35% cover spanning the northeastern, eastern, and central areas and a southwestern stretch through the Lake Edward-George corridor, with an average wind force of 2.5–3 knots. The strength is expected to increase southwards to a >5 knots maxima over the southwestern tip of Lake Victoria in Uganda. The highest variability in windspeeds is forecasted for north Karamoja and the LVB.

At the seasonal scale (Figure 3g–j,l–o), both scenarios agree that the strongest windspeed distribution and variability will occur during the dry DJF season, especially over the Karamoja region and southwestern part of Lake Victoria. The largest range is expected during the JJA season, characterized by <2 knots over northern Uganda and >5 knots over southwestern Lake Victoria.

3.2. Historical and Future Climatology of Humidity over Uganda

Uganda's RH climatology for the period 1980 to 2023, (Figure 4a) can be summarized in four homogenous classes represented by colors: green (highest) to yellow (lowest). Class 1 (green) is associated with very high humidity, >80%, centered over western Lake Victoria and areas within the western section of the Lake Victoria Basin, Rwenzori, Elgon, and the southwestern highland. Class 2 (pear green) is associated with high humidity in the range of 70–80% and engulfs class 1 with north, northwest, west, and eastward sweeps towards Lakes Kyoga, Albert, and Edward and the Kenyan border, respectively. Class 3 (lime green) dominates the regions lying north of 2° latitude, except the northern tip of the country and sections of the Karamoja region in the northeast, with moderate RH in the range 60–70%. The fourth and smallest class (yellow) occupies the northern tip of the country and sections of the Karamoja region, with low humidity in the range <60. In summary, class 1 occupies 15% of the country, while classes 2 and 3 occupy 40% each. The smallest share of 5% is occupied by class 4. Climatologically, the southern as well as highland areas of Uganda are significantly more humid than their northern counterparts, with considerable temporal variations in the highland areas and northern parts of the country.

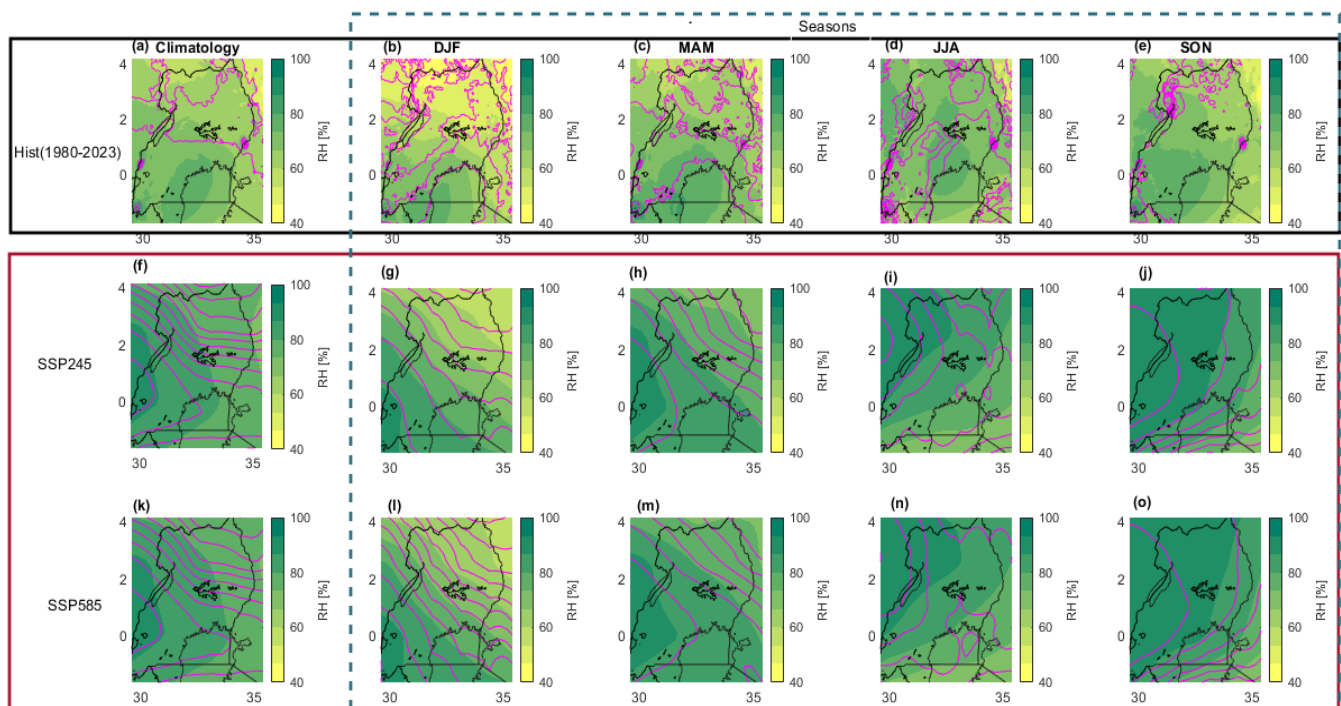


Figure 4. Climatology (a,f,k) and seasonality (b–e,g–j,l–o) of monthly average relative humidity over Uganda for both the historical (a–e) and future (f–o) periods. Magenta contours indicate variability, whose intensity is depicted by contour compactness. Note that contours have slight changes in color appearance due to different color background upon which they are overlaid. This however does not change the meaning and interpretation.

At the seasonal scale (Figure 4b–e), the annual cycle of humidity ends and starts with low humidity during the DJF season. Only a section over the southern tips of the country (within Lake Victoria) with a <5% coverage experiences very high humidity during this time. A significant gain in humidity over the country is observed in the MAM season with a northward trend. The trend continues through the JJA season when almost the entire country has high humidity. However, some southern parts (especially the Lake Victoria area) witness some drying trends, with class 1 centered north of Lake Victoria. SON had the highest RH over the country, with the largest coverage of class 1, spanning the greater

central, western, and southwestern parts of the country. The season is also unique for its RH stability over most parts of the country, except the West Nile and mountainous areas, dominating the areas north of 2° latitude. Humidity is characterized by variability across the seasons.

The future, on the other hand, based on both SSP245 and SSP585, will be dominated by higher humidity in comparison to the past (Figure 4f,k). The scenarios also project a significant change in the distribution of humidity over the country. For example, extreme humidity is forecasted to be centered over the western Rwenzori region, with an eastward decreasing trend. Both scenarios agree on the pattern, with slightly higher humidity predicted in SSP585 compared to SSP245 and a protrusion of class 1 humidity to engulf Lakes Kyoga and Victoria under SSP585. The highest temporal variability in RH is forecasted for areas north of 2° latitude.

At the seasonal scale, Figure 4g–j,l–o under both scenarios agree that the highest humidity will be experienced during the wet SON season, followed by MAM, JJA, and lastly DJF, which is also the only season expected to have low humidity over the Karamoja region. The highest intraseasonal variability is predicted under SSP585 for the DJF season across the country. The highest inter-seasonal range in RH is also expected to be between DJF and SON, especially over the northern part of the country.

3.3. Trends in Humidity and Windspeeds

3.3.1. Long-Term Trends in Humidity

Historically (Figure 5a), RH was decreasing for most parts of the country except over Lake Victoria, the Elgon region, and the Karamoja stretch, where no trends to increasing trends were observed. While the largest part of the country was dominated by decreasing trends, significance was confined within the southern, central, and western parts of the country, with the strongest magnitudes of -0.01 units/month centered over the southeastern part of the Lake Albert Basin (LAB).

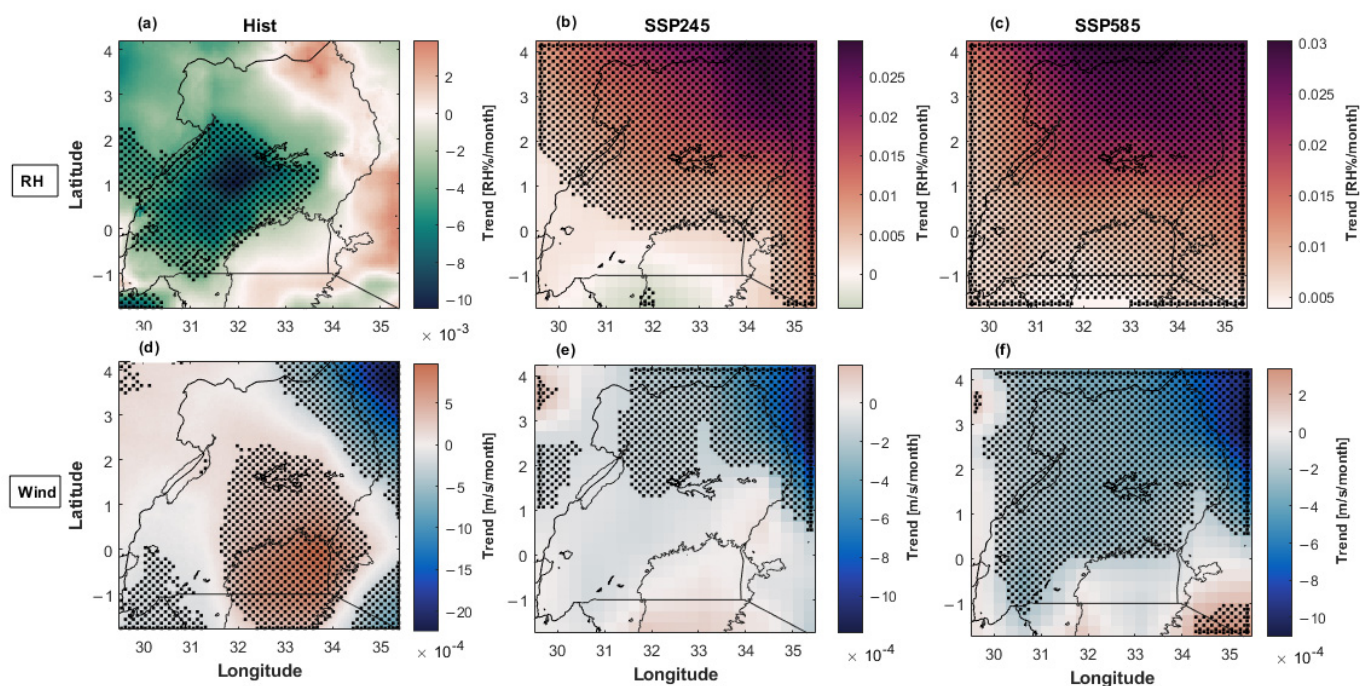


Figure 5. Historical and future long-term trends and magnitudes in relative humidity (a–c) and windspeed (d–f) over Uganda. Stipples indicate significance at 95% level of confidence.

The future, on the other hand (Figure 5b,c), under both SSP245 and SSP585, is predicted to be dominated by significantly increasing trends in RH except under SSP245, where an absence of trends in the Rwenzori region and areas south of the equator is foreseen. Agreement exists on the trend direction between the historical period and future under SSP245 over Lake Victoria and the southwestern tip of the country. The strongest trend magnitudes are forecasted for the Karamoja region and northern Uganda at 0.025 units/month and 0.03 units/month under SSP245 and SSP585, respectively.

3.3.2. Long-Term Trends in Windspeeds

Historically (Figure 5d), windspeeds are observed to have been both increasing and decreasing significantly over the greater Victoria–Kyoga Basin and Karamoja and Kigezi regions, respectively. The modest rest of the country was, however, under stable conditions. The strongest increase was recorded over eastern Lake Victoria at 0.001 knots/month, while the greatest decrease was observed over eastern Karamoja at -0.0015 knots/month.

The future, on the other hand (Figure 5e,f), under both SSP245 and SSP585, is predicted to have an interplay of no trends to decreasing trends. SSP245, for example, predicts a domination of no trends over most parts of the country except the region west of the Albert Nile and north of the Victoria Nile and Lake Kyoga. SSP585 projects larger and the largest coverage of decreasing trends in windspeeds, with stronger magnitudes over 70% of the country. There is a modest agreement in trend direction between the future scenarios over Lake Victoria, Mt. Elgon, the western Lake Victoria Basin, and the Kigezi region in the southwest. Meanwhile, at a periodic level, this agreement only existed between the historical period and future under SSP245. This agreement is observed in areas such as east LKB West Nile, LAB, and west LVB.

3.4. Wind–Humidity Nexus over Uganda

The results regarding the wind and humidity relationship over Uganda for both the historical and future periods are provided in Figure 6. Strong to very strong positive correlations dominate the country, with a 70% coverage. The remaining 30% is shared by moderate to weak positive correlations and no correlations. This is observed especially over Lake Victoria, with a diagonal extension towards Lake Albert in the west. This weak positive correlation pattern is also observed east of Lake Kyoga, with a northward but scattered extension towards north Karamoja.

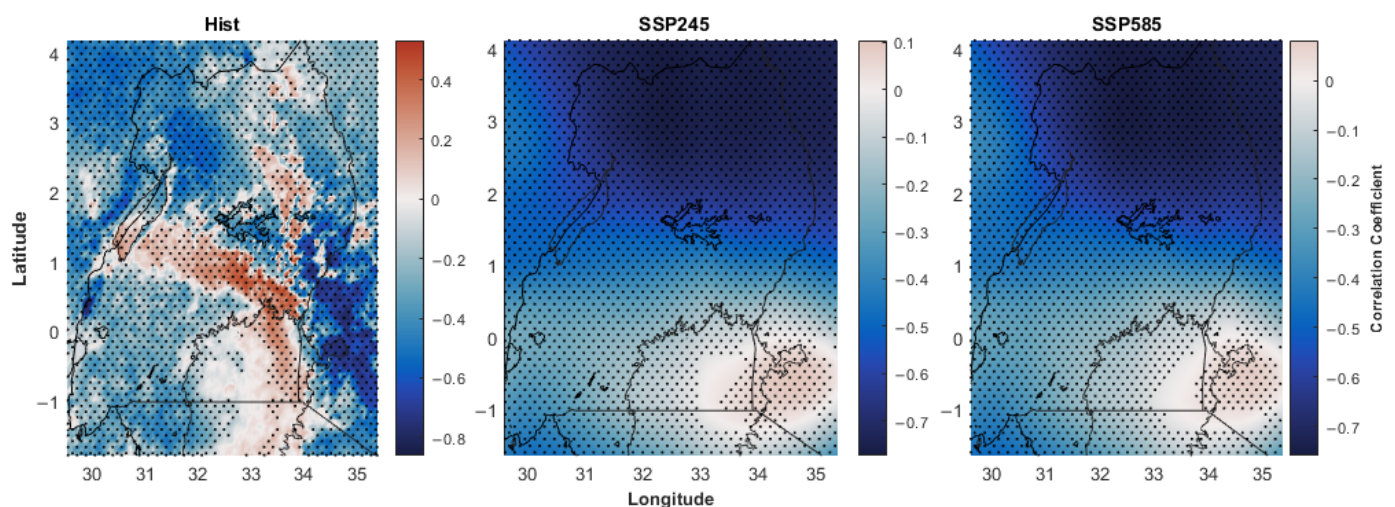


Figure 6. Historical and future correlations between windspeed and relative humidity over Uganda. Stipples indicate significance at 95% level of confidence.

On the other hand, the future relationship under both scenarios is dominated by a stronger negative correlation, both in terms of strength and distribution. For example, only the eastern section of Lake Victoria will maintain a mix of zero and weak positive correlations under SSP245. However, under SSP585, the relationship between humidity and windspeeds is forecasted to diminish completely in the eastern section of Lake Victoria.

At the seasonal scale (Figure 7), the strongest distribution of the negative relationship between windspeed and RH is observed in the dry DJF season, with 90% coverage associated with moderate to strong correlations. The MAM season, on the other hand, is characterized by a balance of positive and negative relationships. For example, moderate positive correlations are observed in areas south of 2° latitude except the Rwenzori and Elgon subregions and some parts of central Uganda during this season. Meanwhile, moderate to strong negative correlations are observed elsewhere. During the JJA season, moderate to strong negative relationships dominate the country, again except for the southwestern part of Uganda and the area within longitudes 33° and 34°, as well as the Mbale region. The SON season is associated with a more pronounced positive correlation within the 33° and 34° band stretch. In this same season, newly established negative and positive correlations are also observed over the southwestern and northwestern parts, respectively.

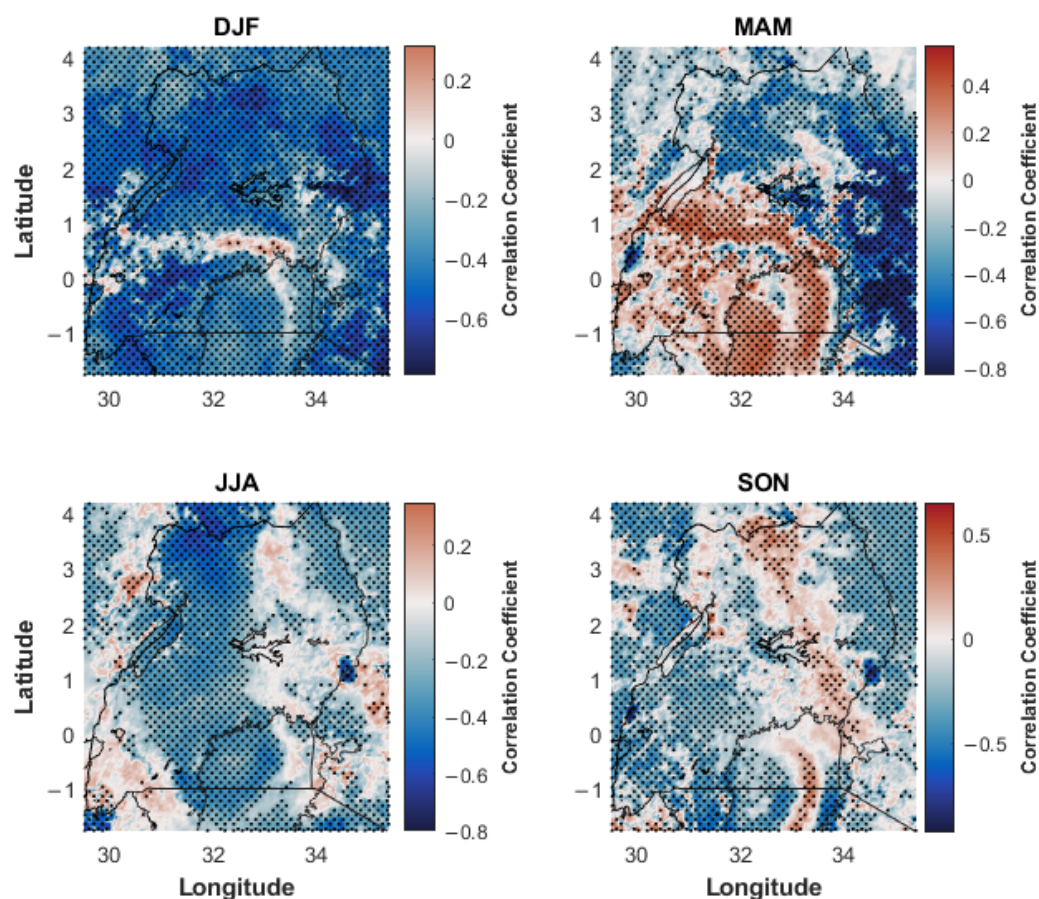


Figure 7. Historical windspeed and relative humidity correlation by season over Uganda.

4. Discussion

4.1. Uganda Windspeed Climatology and Future Dynamics

Uganda's monthly windspeed climatology for the period 1980–2023 was characterized by calm to gentle breezes with modest seasonal variations in both magnitude and distribution. There was a pronounced continuous orientation of the maximum windspeeds over Lake Victoria and eastern Uganda. While the observed pattern and distribution of wind

force over Uganda can generally be attributed to the northeasterlies [19] of Arabian peninsula origin and southeasterlies [64] of Indian Ocean origin, the pronounced strength and orientation can be attributed to both the (i) topography characterized by flatness, ensuring a more smooth day-time boundary layer over both Lake Victoria and the adjacent land mass, and (ii) the lake effect [65] as a result of uneven heating over the lake and adjacent land mass, creating thermal gradients that create both pressure differences and thermal winds. This distribution was also consistent with a study by Pallabazzer and Sebbit [26]. Similarly, the observed calmness over western Uganda and reducing gradient towards the north can be attributed to the distance covered by the Congo air mass and northeasterlies, complex terrain over western Uganda creating friction, and the overall strength and orientation of both the Mascarene and Arabian high-pressure systems. The observed intensification of windspeeds, especially during the MAM and JJA seasons, along with the commencement of the rainfall season over the LVB and LKB, explain the reported reduction in marine safety [66] and occurrence of landslides [31] during these seasons.

The projected change in distribution and associated reduction in wind force under both SSP245 and SSP585 may be a sigh of relief to fishermen and mariners over Lakes Kyoga and Victoria and Elgon highland dwellers. However, this would also translate into a reduction in wind power potential [33] over even the slightly legible islands in Lake Victoria and northeastern Uganda [26]. The reduction would further slow the cooling mechanism of adjacent masses [3] through weakened sea breezes. On the other hand, the projected increase in variability implies increased stochasticity and hence difficulty in accurate operational wind forecasting.

4.2. Uganda Humidity Climatology and Future Dynamics

Uganda's RH climatology for the period 1980–2023 was characterized by high to very high humidity, with significant variations across seasons in terms of both magnitude and distribution. As such, a four-homogenous-class distribution centered over southern Uganda could be realized. This humidity distribution mimics the rainfall distribution [25], especially in the southwestern parts of both the country and Lake Victoria. The observed seasonal variations in humidity can thus be attributed partly to rainfall, as well as temperature [2] seasonality. The observed lower humidity over the Karamoja region during the northern hemisphere winter and spring seasons (DJF and MAM) can be attributed to dry northeasterlies originating from the Arabian winter high that sweeps the little available water vapor over the region. Except in the northern part of country during the DJF season, the year-round high to very high humidity observed across the country, coupled with hot temperatures [36] and a more reliable rainfall distribution [66], make Uganda a hot and humid country with high agricultural suitability attributes. On the other hand, this also explains the high prevalence of malaria [67] due to the predominance of high humidity and temperatures, which favor malaria [35].

The projected change in distribution and associated increase in RH under both SSP245 and SSP585 may be of great benefit to farmers and pastoralists, especially in the northern parts of the country, as an increase in RH would offset the moisture deficit [8] in the atmosphere, hence reducing evaporation, a major output of water from Earth's surface, thus preserving moisture. A case in point is the projected increase in suitability of major cash crops such as coffee [68] in Uganda for the near future. This shift in spatial pattern and trend is, on the contrary, expected to exacerbate the poor health conditions of the inhabitants of the northern part of the country by intensifying heat stress [69], increasing the suitability of vector-borne and zoonotic diseases such as plague [70].

4.3. The Wind–Humidity Nexus over Uganda

Wind and humidity assume a moderate to strong anti-correlation for the largest part of the country, with an intensification under future climatic change. This relationship is in line with various studies on the humidity and windspeed relationship globally, including but not limited to Bailey et al. [71], Zakaria et al. [72], and Siloko and Uddin [73], among others. This inverse relationship can largely be explained by wind's primary role of transporting energy and momentum both horizontally and vertically in the atmosphere [1]. Thus, an increase in wind flow(speed) is associated with a proportionate outflow of energy in the form of moisture [74], hence the reduction in RH. Similarly, depending on its origin, wind also transports moisture to areas or regions devoid of it. This explains the observed positive Lake Victoria–Lake Albert correlation and its more pronounced establishment during the wet MAM season, thus revealing the maritime characteristics and behavior of the Congo westerlies and north- and southeast trade winds during MAM and SON. The observed orientation and strength of humidity class 1 can suitably map and consequently explain the convergence zone of both southeast [64] and northeast [20] trade winds during the East African monsoon season and its associated dynamics.

Overall, the observed strong relationship between windspeed and RH over Uganda opens a window to a better understanding of surface circulations and also paves the way for improvement in their forecasting, with vital applications in agriculture, hydrology, urban meteorology, disaster management, and energy resource modeling.

5. Conclusions

This study demystified both the dynamics and nexus of windspeeds and relative humidity over the historical (1980–2023) and future (2025–2040) periods at a monthly resolution. While at the monthly scale windspeeds across Uganda do not vary significantly, the observed changes call for action, especially in areas surrounding Lake Victoria, where the strongest magnitudes are observed, characterized by increasing trends over the past period. For example, enhancing localized weather forecasting and mobile-based warning systems could improve the safety of fishermen and seafarers. Humidity, on the other hand, exhibited distinctions, especially between the northern and southern parts of the country, including significant patterns and magnitude changes dominated by increases in the future. This likewise calls for action, especially in the northern part of the country where the forecasted significant increase in humidity is expected to open the region for extensive agriculture. Lake Victoria plays a dominant role in the distribution and dynamics of both windspeed and humidity over Uganda. Windspeeds have a strong negative association with atmospheric wetness or dryness over Uganda. Finally, we recommend further studies that incorporate wind direction and air temperature at fine scales and over multiple vertical layers of the atmosphere and for extended future periods and scenarios.

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