# The Nexuses between Wind and Rainfall Patterns: Using Wind to Predict Rainfall for Enhanced Adaptability to Rainfall Related Hazards

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**ABSTRACT:** *The ability to predict rainfall patterns is crucial for making informed decisions on proper adaptation to extreme climatic events like floods and droughts. This study assessed ways through which wind direction and speed could be used to predict the nearness of the beginning and end of the rainy season and the amount of rainfall expected to be received during the rainy season. The study was conducted in Mwanga District in Kilimanjaro Region, Tanzania. It used local perceptions on the nexus between wind and rainfall patterns collected through structured and in-depth interviews involving 110 and 19 respondents, respectively. The local perceptions were corroborated with findings from data on rainfall and wind of the period from 1962 to 2021. It was found that wind tended to blow from the east most of the time and from the south during the long rainy season. Farmers can use the direction of wind to predict the nearness of the beginning and end of the rainy season. If they find that wind blows from the abnormal direction at the beginning of the rainy season, they conclude that the rainy season is yet to begin. Besides, if wind continues blowing from the abnormal direction, after the rainy season has begun, they conclude that rainfall will be less than normal. Further, occurrence of cyclones during the dry season indicates that the short rainy season will start soon. If the frequency of the cyclones is high, then heavy rains will be received. Thus, wind is an important element of weather that could be used to predict the beginning and end of the rainy season as well as the amount of rainfall that will be received. It is, therefore, important that this local knowledge is formally recognized so that it can be used by as many people as possible. Moreover, the local predictions of the pattern of rainfall based on wind should be integrated with modern forecasts to improve the reliability of the predictions at local level. This will lead to the making of informed decisions on adaptation to rainfall-related hazards, and improvement of adaptability and resilience to such hazards.*

**KEY WORDS:** Wind direction, wind speed, rainfall patterns, prediction, adaptability

## INTRODUCTION

Being the main source of food, raw materials and exports for foreign currency, agriculture is the backbone of the economies of many developing countries [1,2]. Despite this importance, agriculture is predominantly rain-fed [3]. Therefore, climate change and the attendant variability affect its development. Heavy rains and the associated floods as well as droughts are the most frequently recurring and detrimental climatic events that affect crop and pastoral farming in sub-Saharan Africa. With regard to drought, studies have reported a remarkable increase of drought in terms of frequency, intensity, duration, and spatial coverage since the last part of the 19$^{th}$ century [4,5,6]. For instance, Touchan and colleague in 2011 reported that the frequency of the occurrence of a single drought event in Tunisia, Morocco, and Algeria increased to 19 times per century during the 20$^{th}$ century from 12 to 16 times before the 20$^{th}$ century [5]. Drought affects crop production and pastoral farming due to the shortage of soil moisture that causes crop-water stress and a shortage of pastures. Various studies have shown that drought is among the most important threats to livelihoods in certain parts of Tanzania [7,3]. Climate change has also been causing heavy rains and floods, which, among other effects, destroy crops.

Farmers' adaptation to the effects of climate change and the associated extreme climatic events is very important for socio-economic development, because it helps to moderate the effects and exploit the associated beneficial opportunities [8]. Nonetheless, such adaptation depends, to a large extent, on the ability to accurately and timely predict the occurrence of extreme climatic events. Whenever farmers have accurate information on predicted event(s) or have the ability to predict them at a reasonable level of accuracy, they make informed decisions on adaptation. Such farmers may decide to change planting dates, plant early-maturing seed varieties, change crop varieties, shift livestock to other locations, or sell some of their livestock before difficult times begin, depending on the nature of the predicted event [9,10].

Various ways of predicting climate/weather events are available, including modern methods used by meteorological authorities and traditional methods. While modern methods are very useful and reliable, information from reliable sources may not be easily accessible, especially in rural areas [11]. Thus, traditional and local methods of predicting the weather are still important to improving local communities' adaptation to climatic hazards. Various traditional methods are used to predict the weather, including observing the nature and pattern of clouds, stars, vegetation, birds, animals, and wind [12,13]. However, the accuracy of these local methods is not well known. This paper focuses on the effectiveness of using wind patterns in predicting the beginning and end of the rainy season, and the amount of rainfall to be received in the rainy season, which is associated with extreme climatic events like drought and floods.

Wind is an important element with regard to climate change in general and to rainfall patterns in particular. Essentially, wind is at the center of climate and climate change-related equations; wind is affected by variations in temperature and, in turn, affects rainfall patterns. Generally, the global climate systems begin with solar radiation emitted by the sun and received in the thermosphere. The amount of solar radiation received when the earth is at average distance from the sun (solar constant) is 1372 W/m$^2$ (watts per square metre) [6]. Although this is just a tiny fraction (two billionths) of the sun's total energy output, it is an extremely high amount to reach the planet earth. As such, some amount of solar radiation is reflected or scattered as shortwave radiation in the atmosphere [14,6]. The thermosphere and mesosphere (functionally known as the ionosphere) absorb cosmic rays, gamma rays, x-rays, and some ultraviolet (UV) radiations. The remaining harmful UV radiation (UVC at 100-290 nanometers (nm) and some UVB at 290-320nm) is absorbed by the ozone layer [14]. Thus, only UVA at 320-400nm and the visible light proceeds to the earth's surface. Besides, some amount of solar radiation is scattered by gas molecules, dust particles, pollen, smokes, and water vapor in the atmosphere [14].

After these processes, only 48% of the solar constant reaches the earth's surface [6]. The earth's features absorb the energy and re-emit it as thermal infrared radiation (TIR). Some TIR is absorbed in the atmosphere by greenhouse gases (GHGs), including carbon dioxide ($CO_2$), methane ($CH_4$), water vapor, and oxides of nitrogen, which warm the earth system so that it is of the required level (greenhouse effect) [6]. Thus, an increase in GHGs like $CO_2$ in the atmosphere increases the amount of TIR retained in the atmosphere, thereby causing a rise in temperature on the earth's surface. Increased temperature affects pressure belts, thus leading to changes in the circulation of wind.

Wind plays a great role in the formation of rainfall; when wind is blowing from moist-rich environments it brings a moist air mass, thus causing rainfall. Moreover, in order for rain to fall, wind must force the moist and warm air mass to ascend so that it encounters small pressure, thereby leading to adiabatic cooling, condensation, and finally rainfall [15,6]. Like other elements of weather, wind, that is, the speed and direction of wind, has been changing with climate change. The speed of wind has been increasing or decreasing over time in some areas, and the direction of wind has been shifting from normal to abnormal in particular periods of time [16,17]. Depending on the prevailing conditions, these changes in wind patterns can bring about rainfall or drought conditions. Thus, observing the direction and speed of wind could be a useful tool in predicting the nature of rainfall in the rainy season. Using Mwanga District as a case study, this research examined the nexus between wind and rainfall patterns to improve local communities' capacity to adapt to extreme weather events (drought and heavy rainfall) through reliable predictions of their occurrences.

## RESEARCH METHODS

### Research Design

The study deployed a mixed research design and was informed by a pragmatic philosophy, which allows for the triangulation of methods to understand a research problem well [18]. The design was useful because the study needed both quantitative and qualitative data.

### Area of the Study and Justification

This study was conducted in Mwanga District, one of the seven districts of Kilimanjaro Region in Tanzania. The district lies between 3°25′ and 3°55′ south of the Equator, and 37°25′ and 37°58′

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east of the Greenwich Meridian. It is bordered by Moshi Rural District in the north, the Republic of Kenya in the northeast, Same District in the south, and Simanjiro District of Manyara Region in the west. The district covers an area of 2,641 square km, which is about 20% of the total area of the region, which is 13,209 square km [19]. Mwanga is a semi-arid district and experiences strong winds [20]. The semi-aridity climatic conditions make the district prone to extreme climatic events, especially droughts. Thus, the district was considered a suitable area in which to study the relationship between wind and rainfall patterns.

**Sample and Sampling Procedures**

Mwanga District is divided into lowland and highland ecological zones, with the lowland zone experiencing more strong winds than the highland zone does. As such, this study was conducted in the lowland zone, where local knowledge regarding the relationship between wind and rainfall could be easily studied. Besides, this area is near the meteorological station where meteorological data could be obtained. Two wards that are near the meteorological station were purposefully selected, and one village from each ward was randomly selected. The wards were Lembeni and Mgagao, and the villages were Mangara and Mgagao, respectively. The Village Executive Officers of the two villages were requested to provide a list of all the households to obtain a sampling frame for determining the sample size and selection of the sample. The two villages had a total of 1,095 households: 514 in Mangara village and 581 in Mgagao village. 10% of the households were regarded as manageable and enough for doing a statistical analysis. Thus, 110 households were systematically selected and structured interviews were held with them. The number of respondents from each village was determined using proportionate stratified sampling. Proportionate stratified sampling made it possible to select a proportional number of respondents from each village, depending on the size of its population (Table 1).

**Table 1: A Proportional Sample for Each Village**

| Ward | Village | Number of Households | Sample Size for Each Village |
|---|---|---|---|
| Lembeni | Mangara | 514 | 514/1,095 x 110 = 52 |
| Mgagao | Mgagao | 581 | 581/1,095 x 110 = 58 |
| | **Total** | **1,095** | **110** |

Nineteen key informants were purposefully selected. Out of these, 11 came from Mgagao village and eight from Lembeni village. These were selected owing to their knowledge of the phenomena studied and their willingness to participate in the in-depth interviews.

**Data Types and Data Collection Methods**

Data for this study included local perceptions on the nature of wind and rainfall, as well as the ways through which the direction and speed of wind could be used to predict rainfall. The data were collected from 129 respondents, 110 of whom were interviewed during structured interviews and 19 participated in in-depth interviews. Moreover, data on rainfall and wind were collected from the Tanzania Meteorological Authority (TMA). Information on heavy rains and droughts seasons for long rain seasons (MAM) and short rain seasons (OND) was obtained from data on rainfall, and information on the speed and direction of wind was obtained from data on wind. The latter data included wind-roses that presented wind patterns for the selected periods of time. A wind-rose is a diagram that portrays graphically the speed and direction of wind in a particular location over a period of time. The diagrams for February and September, before the onset of the MAM and OND seasons for the selected years, were collected from the TMA.

**Data Analysis Techniques**

The data on rainfall from the TMA were analyzed first to determine the seasons with above normal rainfall and those with drought conditions. These seasons were the ones of which further analysis was done. The data on rainfall were analyzed using the Percent of Normal Precipitation Index (PNPI), which provides percentage deviations of actual rainfall from normal rainfall in an area [21]. The PNPI is given below:

$$\text{PNPI} = \frac{\text{Actual Rainfall} - \text{Normal Rainfall}}{\text{Normal Rainfall}} \times 100$$ [21].

Accordingly, rainfall deviations ranging from 20% to -20% are considered normal, while rainfall deviations above 20% are regarded as being above normal rainfall and below -20% as being below normal rainfall (drought).

The wind-roses for February and September that preceded the seasons that received heavy rainfall and droughts were analyzed to understand the frequency with which wind blows from a particular direction as well as the speed at which the wind is blowing. The wind-rose diagrams used in this study comprised eight radiating spokes representing the direction of wind based on the cardinal directions (North, East, South, West, North-East, North-West, South-East and South-West). In wind-roses, a spoke pointing to the east, for instance, indicates that the wind is blowing from the east at a particular moment. Moreover, the scale provided with wind-roses helped to determine the percentage of time when wind blows at a particular speed from a particular direction.

The quantitative data collected using structured interviews were analyzed using descriptive statistics, whereas the qualitative data collected using in-depth interviews were analyzed qualitatively. The latter analysis involved describing and classifying data, as well as finding connections between various themes [22].

## RESEARCH FINDINGS AND DISCUSSION

**Rainfall Patterns in the Study Area**

The data on rainfall analyzed indicates that the normal rainfall for the area was 560.4mm for a period of 60 years, that is, from 1962 to 2021, and that it was 527.7mm for a period of 30 years, from 1992 to 2021. This implies that, on average, the amount of rainfall has been decreasing in the area. Besides, these findings indicate that the area experiences semi-aridity climatic conditions which is in tune with Charles and colleague who found that the lowland areas of Mwanga District are semi-arid, receiving 400-600mm of rainfall per annum [20]. Accordingly, the highland areas are relatively wet and receive between 800mm and 1250mm of rainfall [20].

The district has two rainy seasons: the long rainy season of March, April, and May (MAM), and the short rainy season of October, November, and December (OND). The findings from the in-depth interviews with the key informants indicate that the highland areas have both the long and short rainy seasons, and that the lowland areas receives much rainfall during the long rainy season. The normal (average) rainfall for the long rainy season for a period of 30 years, that is, from 1992 to 2021, is 240.2mm, and that of the short rainy season for the same period is 170.0mm. Figure 1 indicates the percentage of normal precipitation index (PNPI) for the period from 1992 to 2021 for both the MAM and OND seasons.

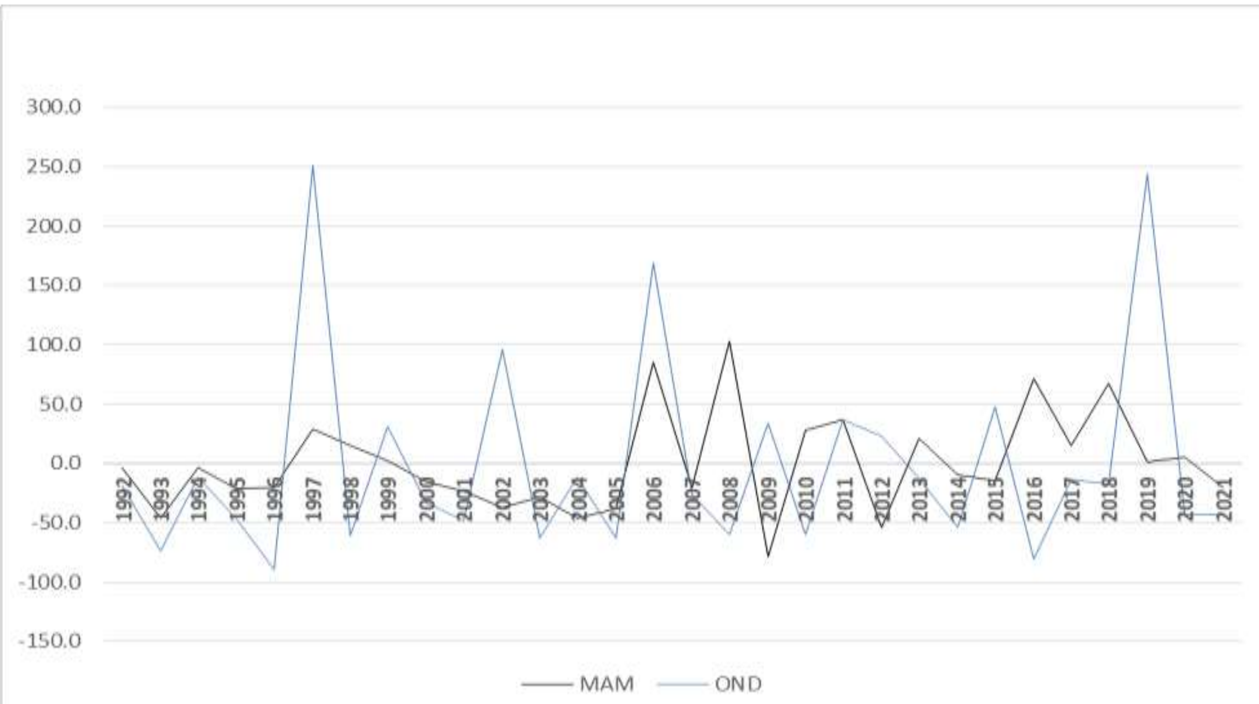


**Figure 1:** Values of the PNPI for 30 Years, from 1992 to 2021, for the MAM and OND Seasons

According to Figure 1, 10 years had normal MAM, eight had above normal MAM, and 11 had below normal MAM (drought). The drought years during the MAM season were 1993, 1995, 1996, 2001, 2002, 2003, 2004, 2005, 2007, 2009, and 2012. Regarding the OND, there were six normal seasons, nine above normal seasons, and 13 below normal seasons (drought seasons). The drought years for the OND were 1993, 1995, 1996, 1998, 2000, 2001, 2003, 2005, 2007, 2008, 2010, 2014, and 2016. Thus, the lowland areas of Mwanga District experience drought frequently.

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**Wind Patterns**

Local perceptions on the direction of wind indicated that wind tended to blow from the east to the west most of the time. However, during the long rainy season wind blew from the south and the southwest. These local perceptions were compared with the findings on the observation of wind-roses for the selected years and months (see Figures 2 and 3). The selection of the years was based on the amount of rainfall as presented in the preceding section, from which two years with normal rainfall, two with above normal rainfall, and two with below normal rainfall for both the MAM and OND seasons were selected. The years selected for the normal rainfall category were those closest to the mean, while the years selected for the above and below normal rainfall were those with extreme indices: the wettest and driest years (Table 2). Besides, the wind-roses for February and September were selected because the months precede the onset of both the MAM and OND seasons.

**Table 2: Years whose Wind-roses were Observed**

| Season | Rainfall Pattern (based on the PNPI - Figure 1) | Year |
|---|---|---|
| MAM | Normal | 1999 |
| | Normal | 2019 |
| | Above normal (wet) | 2008 |
| | Above normal (wet) | 2016 |
| | Below normal (drought) | 2009 |
| | Below normal (drought) | 2012 |
| OND | Normal | 1994 |
| | Normal | 2004 |
| | Above normal (wet) | 1997 |
| | Above normal (wet) | 2019 |
| | Below normal (drought) | 1996 |
| | Below normal (drought) | 2016 |

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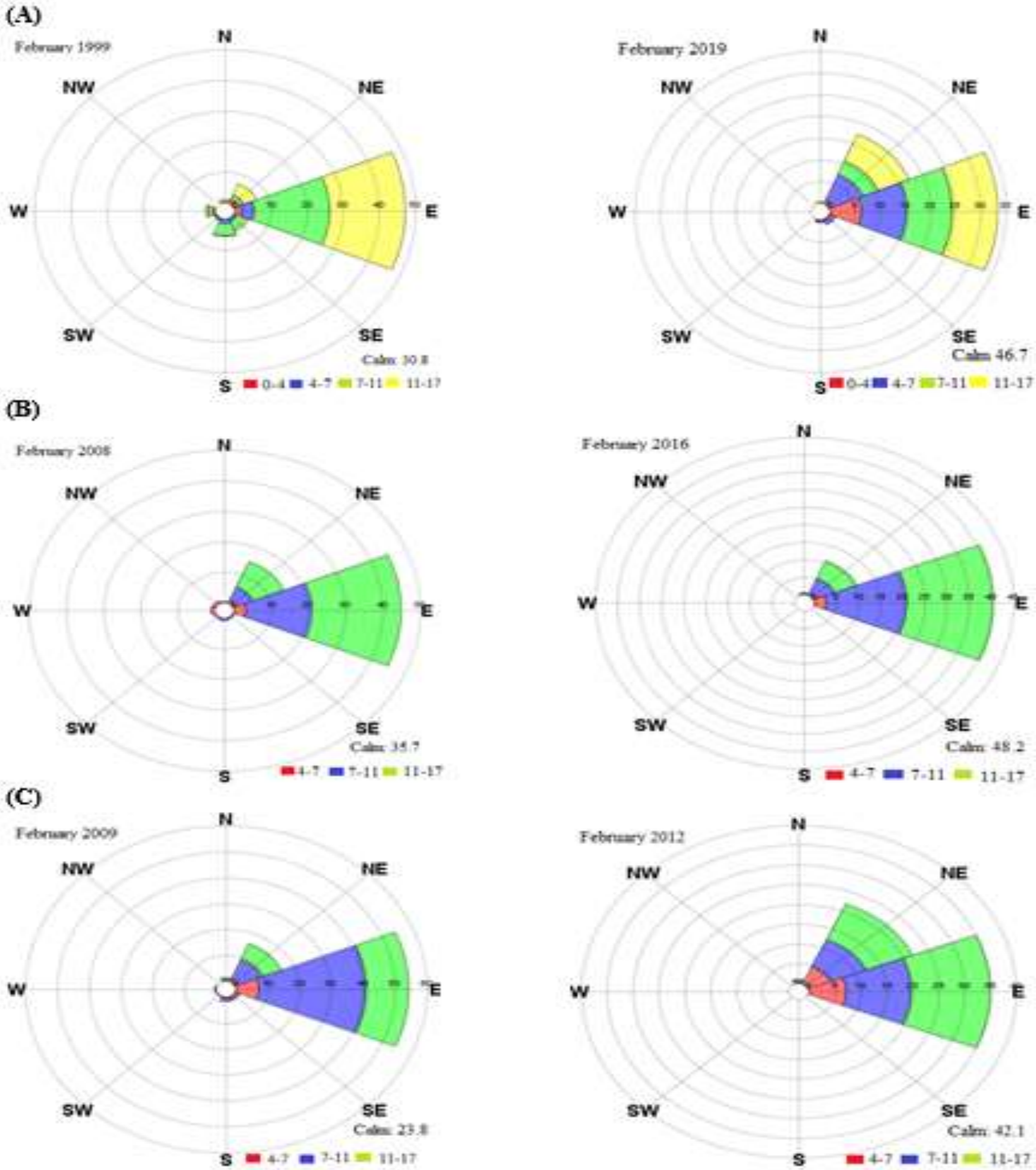


**Figure 2: Wind Pattern for the Years with Normal Rainfall (A), Above Normal Rainfall (B) and Below Normal Rainfall (C) during the MAM Season**

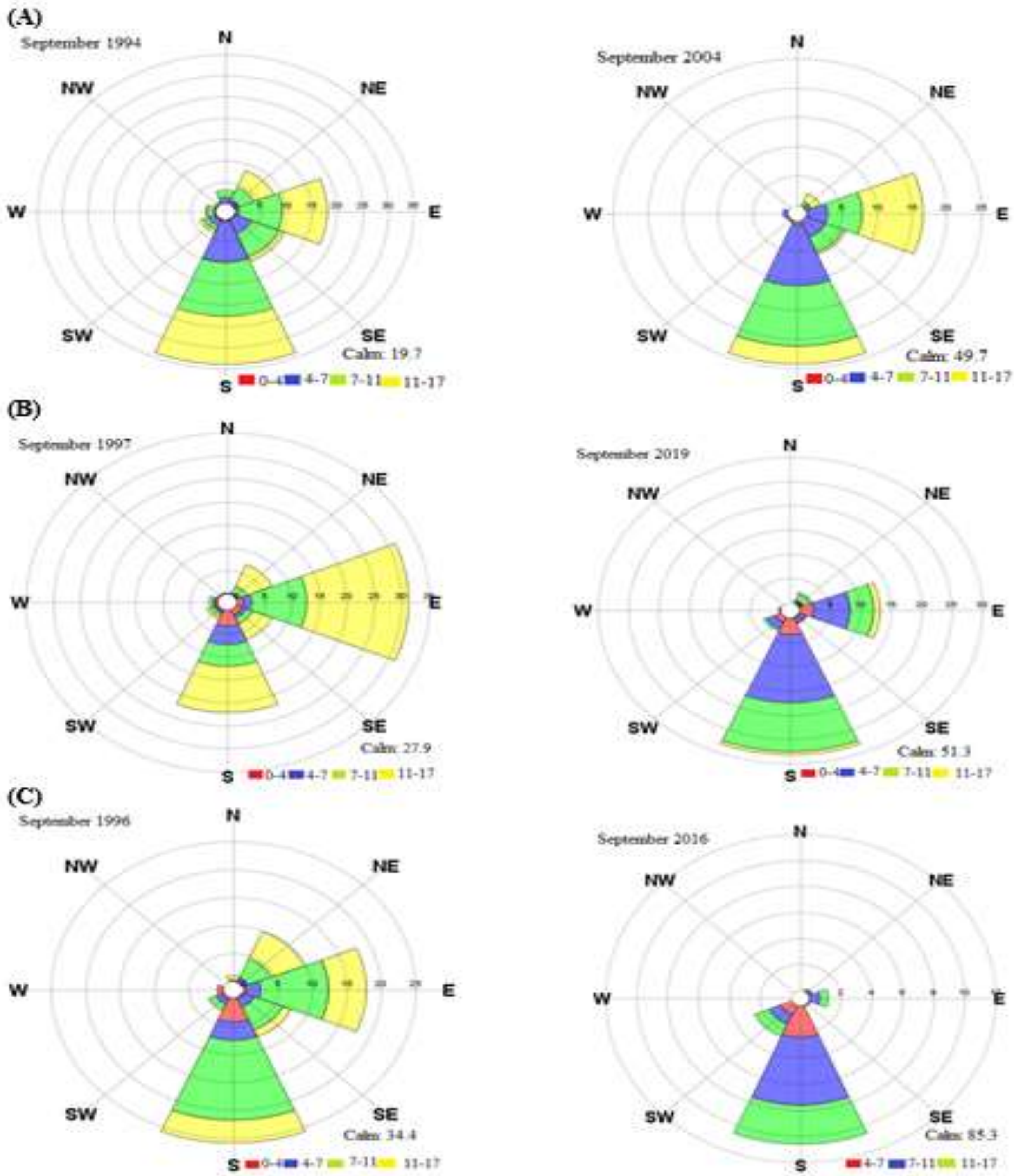


**Figure 3: Wind Pattern for the Years with Normal Rainfall (A), Above Normal Rainfall (B) and Below Normal Rainfall (C) during the OND Season**

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As Figures 2 and 3 show, generally, wind blows from the east in February and from the east and the south in September. The findings on the dominance of the direction of wind from the east to the west agree with those of Charles and colleagues which showed that wind mostly blows from the east to the west in Mwanga District [20].

Besides, Figures 2 and 3 indicate that wind mostly blows at a speed higher than 13km/h (7 Knots) and rises to as high as 32km/h (17 Knots). The findings from local perceptions on the speed of wind indicate that 89 respondents (equivalent to 80.9% of all the respondents) considered the speed of wind to be very high, 15 (13.6%) considered it to be high, and 6 (5.5%) considered it to be moderate. These findings are supported by a number of road signs indicating crosswinds located in certain places along the Dar es Salaam-Arusha highway in the study area. Thus, this study contends that Mwanga District faces strong winds, a view shared by Charles colleagues [20].

Regarding variations in the speed of wind from the 1980s to the present, 64.6% of the respondents reported that the speed of wind has been increasing over time in the area, 23.6% noted that it has been decreasing, and 11.8% reported that they did not have any knowledge about the trend in the speed of wind in their area. The view of the majority of respondents that the speed of wind has been increasing agrees with the findings on the data on wind analyzed. Figure 4 shows that, from 1972 to the present, the speed of wind has been increasing. In view of these findings, this study contends that the speed of wind has been increasing in the area, because of environmental degradation, particularly deforestation, which was mentioned by the majority of respondents during the in-depth interviews.

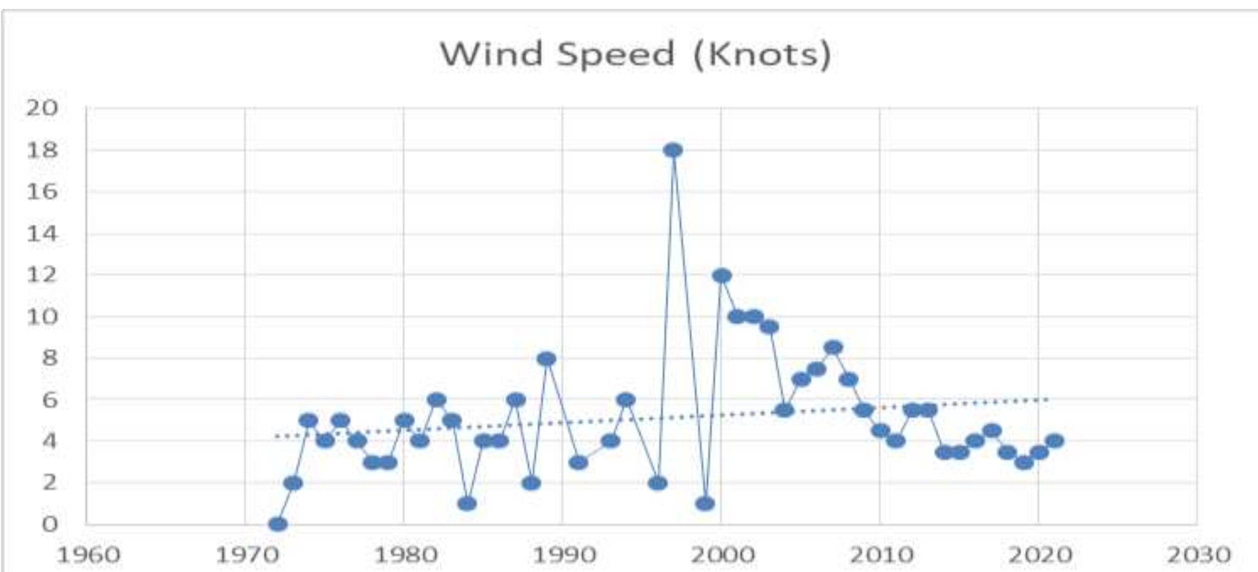

**Figure 4:** Trends in the Speed of Wind in Mwanga District from 1972 to 2021

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### Using Wind to Predict Rainfall Patterns and Related Adaptation Strategies

#### The Direction of Wind

The findings show that the local farmers could predict the characteristics of the rainy season by observing the direction of wind. The characteristics of the rainy season commonly predicted by observing the direction of wind were the nearness of the beginning of the rainy season and the amount of rainfall to be received. Regarding the beginning of the rainy season, the majority of respondents reported that they could observe the direction of wind and tell the nearness of the beginning of the rainy season. Likewise, the elder respondents noted that they normally observed the direction of wind to obtain clues about the onset of the rainy season and to make decisions on the farming activities to do. For instance, if wind is blowing from the east, farmers know that the beginning of MAM is far.

The ability to predict the beginning of the rainy season helps farmers to make decisions on doing various farming activities. For instance, an elder farmer in Mgagao village had this to say regarding the prediction of the beginning of the rainy season using wind and related farming activities, “You cannot undertake dry-soil planting for the MAM while the wind is still blowing from the highlands” (the highland is the area to the east of the area where the study was conducted). Dry-soil planting is a strategy for adapting to early cessation of the rainy season. It involves planting crops in dry soil some days before the onset of the rainy season. According to the above responses, this strategy is used after observing the direction of wind. These findings agree with those of Lana and colleagues who reported that dry-soil planting is useful in capturing the first rains [23].

Besides, the direction of wind (which is associated with the direction from which the rain comes) can tell farmers how much rainfall will be received in a particular season. If it continues raining from the abnormal direction, farmers conclude that the rain may be less than normal. For instance, the farmers in Mwanga know that wind, and therefore rainfall as well, comes from the south during MAM. If it blows from other directions during this period, they conclude that there will be less rainfall. A 55-year-old woman in Mgagao village said, “Many people did not sow seeds because they found that rainfall did not come from the *nyika*, which is the normal direction during the MAM season. *Nyika* is an extensive area which is covered with short trees and shrubs, and which extends southwards from the area where the study was conducted. It was reported to be the normal rainfall direction during the MAM season. According to the above response, knowing that most rainfall did not come from the south, the farmers concluded that it would be less than normal, which was not enough for producing crops. As a result, many farmers did not grow crops during that season.

#### The Speed of Wind

The nexus between the speed of wind and rainfall patterns was not easy to establish. In fact, none of the respondents who participated in the structured interviews said he or she could predict rainfall patterns by observing the speed of wind. However, the majority of respondents who

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participated in the in-depth interviews noted that the occurrence of cyclones signified the beginning of the short rainy season. For instance, an elder farmer in Mgagao village said, "If cyclones occur frequently close to the beginning of the rainy season, then the short rain season will start two or three weeks later." Thus, the farmers use the high frequency of cyclones during the dry season, especially between the long and short rainy seasons, to predict the beginning of the short rainy season.

The above respondent pointed out further that the high frequency of cyclones indicates that much rainfall will be received in the forthcoming short rainy season. As such, cyclones help the farmers to predict the beginning of the rainy season and the amount of rainfall to be received. These predictions help them to decide on the proper farming activities to undertake and on the right adaptation strategies.

## CONCLUSION

Many studies on climate change focus on rainfall and temperature in an attempt to understand the changes happening in the earth's climate systems. Wind is less studied, although it is an important climatic element, which is affected by temperature and which, in turn, affects rainfall. This paper has examined the relationship between the direction and speed of wind on the one hand, and rainfall patterns, on the other, using Mwanga District as a case study. Wind blew from the east most of the time and from the south during the long rainy season in the area where the study was conducted. This was also the case with rainfall, which tended to come from the east during the short rainy season and from the south during the long rainy season. Therefore, the farmers observed the direction of wind to predict the nearness of the beginning of the rainy season. If wind persistently blows from the east to the west, one can predict that the beginning of the long rainy season is still far. Besides, if wind persistently blows from the abnormal direction during the rainy season, the farmers predict with great certainty that the amount of rainfall will be below normal in the season. Further, during the dry season cyclones indicated the beginning of the short rainy season, and a high frequency of cyclones indicated that heavy rain would fall in the forthcoming rainy season. The ability to successfully predict rainfall patterns using such local indicators as wind is important and can be used in complementarity with rainfall forecasts by meteorological authorities, especially in rural areas where the accessibility of the forecast by meteorological authorities is limited. The ability to use wind patterns to predict rainfall patterns in the forthcoming rainy season can help farmers to devise sustainable adaptation strategies, including determining the time to sow seeds and growing drought-tolerant and early-maturing crops.

## References

1. World Bank. (2010). *Agricultural Growth and Poverty Reduction: Additional Evidence*. Washington D.C., World Bank.
2. Msuya, D. G. (2013). Farming Systems and Crop-livestock Land Use Consensus: Tanzanian Perspectives. *Open Journal of Ecology*, Volume 3(7), p 473-481. Available at: http://dx.doi.org/10.4236/oje.2013.37055.

3. Afifi, T. Liwenga, E. and Kwezi, L. (2014). Rainfall-induced crop failure, food insecurity and out-migration in Same-Kilimanjaro, Tanzania. *Journal of Climate and Development*, Volume 6(1), p. 53-60. Available at: http://dx.doi.org/10.1080/17565529.2013.826128.
4. Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, Cambridge University Press.
5. Touchan, R. Anchukaitis, K. J. Meko, D. M. Sabir, M. Attalah, S. and Aloui, A. (2011). Spatiotemporal Drought Variability in Northwestern Africa over the Last Nine Centuries. *Climate Dynamics*, Volume 37(2011), p. 237–252. Available at: https://link.springer.com/article/10.1007/s00382-010-0804-4.
6. Christopherson, R. W. (2012). *Geosystems: An Introduction to Physical Geography*. 8th ed. Upper Saddle River, USA: Pearson Education, Inc.
7. Mbilinyi, A. Saibul, G. O. and Kazi, V. (2013). Impact of Climate Change to Small Scale Farmers: Voices of Farmers in Village Communities in Tanzania.*The Economic and Social Research Foundation*. Available at: www.esrftz.org.
8. Rizvi, A. R. Baig, S. Barrow, E. and Kumar, C. (2015). *Synergies between Climate Mitigation and Adaptation in Forest Landscape Restoration.* International Union for Conservation of Nature and Natural Resources. Gland, Switzerland.
9. Gbetibouo, G. A. (2009). *Understanding Farmers' Perceptions and Adaptations to Climate Change and Variability: The Case of the Limpopo Basin, South Africa*. International Food Policy Research Institute.
10. Msambichaka, S. and Onyango, P. (2019). The dynamics of pastoral mobility routes in relation to food security in semi-arid areas of Simanjiro and Handeni districts in Tanzania.*African Journal of Environmental Science and Technology*, Vol. 13 (10), p. 381-392. DOI: 10.5897 /AJEST 2019.2730.
11. Mosha, G, Lotegelwaki, O. M. and Nyakwaka, D. O. M, (2018). Information Needs and Sources of Maasai Pastoralists at Orkesumet in Simanjiro District Manyara Region –Tanzania, *Library Philosophy and Practice (e-journal). 1882*. Available at http://digitalcommons.unl.edu/libphilprac/1882.
12. Ayall D. Y. Desta, S. Gebru, G, Kinyangi J, Recha J. and Radeny M. (2015). Opportunities and challenges of indigenous biotic weather forecasting among the Borena herders of southern Ethiopia. Springer Plus; A Springer Open Journal Volume 4 (617)
13. Rautela P. and Karkim B. (2015). Weather Forecasting: Traditional Knowledge of the People of Uttarakhand Himalaya. *Journal of Geography, Environment and Earth Science International* Volume 3(3): p. 1-14.
14. Holden, J. (2011). *Physical Geography; The Basics.* New York, Routledge.
15. Bravar, L. and Kavvas, M. L. (1991). On the Physics of Drought: A Conceptual Framework. *Journal of Hydrology*, Volume 129(1991), p. 281-297.
16. Christopherson R. W. and Birkeland G. H. (2017). Geosystems: An Introduction to Physical Geography. 10th ed. Upper Saddle River, USA: Pearson Education, Inc.

17. Davy, R., Gnatiuk, N., Pettersson, L., and Bobylev, L. (2018). Climate change impacts on wind energy potential in the European domain with a focus on the Black Sea. *Renewable and Sustainable Energy Reviews, 81*, 1652–1659. doi:10.1016/j.rser.2017.05.253.
18. Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches.* 3rd ed. New Delhi, SAGE Publications, Inc.
19. United Republic of Tanzania (URT). (1998). *Kilimanjaro Region Socio-Economic Profile*. Ministry of State Planning and Parastatal Sector Reform. Dar es Salaam, Tanzania.
20. Charles, R. L., Munishi P. K. T. and Nzunda, E. F. (2013). Agroforestry as Adaptation Strategy under Climate Change in Mwanga District, Kilimanjaro, Tanzania. *International Journal of Environmental Protection* Volume 3 (11): p. 29-38 – 29.
21. Kumar, M. N. Murthy, C. S. Sesha Sai, M. V. and Roy, P. S. (2009). On the use of Standardized Precipitation Index (SPI) for drought intensity assessment. *Meteorological Applications*, Volume 16, Available at: https://doi.org/10.1002/met.136.
22. Kitchin, R. and Tate, N. J. (2000). Conducting Research in Human Geography: Theory, Methodology and Practice. London, Pearson Education Limited.
23. Lana, M. A. Vasconcelos, A. C. Gornott, C. Schaffert, A. Bonatti, M. Volk, J. Graef, F. Kersebaum, K. C and Sieber, S. (2017). Is dry soil planting an adaptation strategy for maize cultivation in semi-arid Tanzania? *Food Security*. Available at: https://doi.org/10.1007/s12571-017-0742-7.