Monthly and Seasonal Variation of Cloud Cover, Humidity and Rainfall in Lagos, Nigeria

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Abstract: - The study of atmospheric variables such as cloud cover, humidity, and rainfall is needed to forecast/predict the weather to enhance policies implemented by the government concerning agriculture, water resources, and other relevant industries in Lagos State (6.45°N, 3.39°E), Southwest Nigeria. There is a need to ascertain the variability in cloud cover with other meteorological parameters in Lagos State which is fast-growing with a total land mass of 1,171.28 square kilometers. Eleven years (2011-2021) ground data obtained from Visual Crossing a leading provider of weather data were analyzed on a monthly and seasonal basis using statistical tools. The results show that there is a significant rise in the extent of cloud cover in Lagos during July to September, with September being the peak month due to about sixty-three percent (63%) of the sky being cloudy in September. However, there is the minimum amount of cloud cover observed between December and February, with January being the least month about forty-one percent (41%) of the sky cloud-covered in the average year. Lagos experiences a yearly average humidity of 83.5% from June to October, peaks in September (87.88%), while the lowest value (77.26%) occurs in January. The annual average rainfall accumulation for the eleven (11) years is recorded to be 1611.30 mm. In June, September, and October, the rainfall rate is recorded to be very high with values that range between 242.53 mm, 227.25 mm, and 233.86 mm respectively, while December and January is observed to record the lowest accumulation of rainfall with values that ranges between 27.26 mm & 27.97 mm respectively. Finally, the comparison of the linear regression trend and the estimated Pearson correlation coefficient reveals a substantial, positive relationship exists between cloud cover and humidity, although cloud cover has a minor influence on rainfall. According to the study's findings, it is advised that rainfall awareness programs be expanded and that government policies relating to agriculture, water resources, and other relevant sectors take into account the rising nature of rainfall in recent years.

Key-Words: - Atmospheric variables, Correlation, Cloud cover, Attenuation, meteorology, Humidity, Rainfall.

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1 Introduction

Meteorology defines "cloud" as an aerosol composed of small droplets, ice crystals, or other particles suspended in the atmospheres of planets or other similar environments. The droplets and crystals could be made of water or something else, like ice. For clouds to form, air gets saturated at the dew point or collects moisture above the ambient temperature, [1]. Cloud cover is the most significant meteorological variable because it affects how far solar radiation may travel before reaching the Earth's surface, whereas clear skies have less of an impact, [2], [3].

According to multiple climate models, rising water vapor in the atmosphere due to global warming is expected to increase the greenhouse effect, which in turn is expected to increase the vicious feedback loop that is already occurring, [4]. As a result, precipitation has increased in the world's mid- and high-latitude regions, [5]. Specific humidity in the atmosphere is frequently expressed in terms of specific humidity units (SHU) and relative humidity units (RH). The ratio of water vapor in the atmosphere to air capacity at a given temperature. RH has the potential to have a direct impact on plant development and human well-being, [6]. The RH, on the other hand, is better suited for researching climate feedback. When it comes to affecting particle concentration and aerosol radiation properties, RH is an important factor, and this in turn has an impact on air quality and visibility, [7].

Among all the variables, rainfall received in an area is one of the key variables for studying climatic variability and further planning socio-economic development strategies accordingly. The IPCC's third assessment report shows that the global hydrological cycle will become more intense as a result of climate change, which will affect both ground and surface water supply, [8]. To plan and manage water resources, one must comprehend the dynamic character of the climate. Since rainfall plays a crucial role in agriculture, water resources, hydroelectric power generation, and the economy of the region, along with annual and seasonal variation, monthly rainfall, alongside that of cloud cover and humidity, also plays an important role in planning purposes.

1.1 Description of Clouds

Observations with powerful telescopes on the ground and in space have shown that planets with a lot of water or an atmosphere, like Venus, Mars, Jupiter, and Saturn in our solar system or similar systems in distant galaxies, form clouds around the planet's surface when they are placed at an appropriate distance from their star. There is a fundamental connection between clouds, the three known phases of water, and the perplexing chemical composition of water and water molecules. As Masaru Emoto has proved via his experiments and knowledge, ice crystals generated from water in different places throughout the world exhibit strange differences in their structure, shape, symmetry, and size. In addition to being puzzling and strange, these findings defy all reasonable explanations, [1].

It's impossible to know for sure, but Rupert Sheldrake's work on regional variations in morphogenetic fields may have contributed to these discrepancies, [9]. Even though they are more like blanket layers of gaseous masses than actual clouds, large volumes of gases like carbon dioxide, methane, ammonia, etc. have been referred to as "gaseous clouds" in the literature without regard to context, [10]. In the past, it was thought that clouds formed on Earth as a result of water evaporation from seas and lakes, animal metabolism, and evaporation from forests, crop canopies, and sea algae. Thus, evaporating water crystallizes into microscopic particles between 20 and 60 microns in size and then forms opaque porous masses called clouds as a result of precipitation and cooling. Clouds can take on the most bizarre, gorgeous, and unusual shapes.

Water moves vertically above sea level more quickly as a result of low-pressure air systems, heat convection, mechanical instability, ascent across steep terrain, and the funnel influence. The World Meteorological Organization (WMO) has divided clouds into four categories based on height above sea level: A, B, C, and D. Luke Howard, a young, unidentified English pharmacist, first proposed this classification in 1802; it has since undergone several minor modifications. Clouds have been seen rising as high as 16 kilometers in the air, [11]. In 1803, Luke Howard named several different kinds of clouds, earning him the title of "father of modern meteorology." Moisture content, clouds, precipitation, climate, and weather all play a role in meteorology's origins. A meteorologist, for example, would be rendered useless in a world devoid of the atmosphere or water.

Clouds are formed by the condensation of ice and water droplets. The droplets' nucleus is made up of dust particles. Fog is formed near the ground, whereas clouds are formed in the open air. Small water droplets and/or ice specks floating in the air are known as clouds, and they are typically visible above the surface of the earth. The presence of moisture in the air is essential for the formation of clouds. In the atmosphere, tiny particles such as dust, smoke, and salt crystals are just a few examples of what causes clouds to form. These components are referred to as Cloud Condensation Nuclei (CCN). Clouds cannot form without them. Ice nuclei are formed when droplets freeze or ice crystals form directly from water vapor on certain surfaces, [12]. In general, there are a lot of condensation nuclei in the air, but there aren't many that are specifically used to produce ice. Hundreds of millions of these minuscule water droplets, ice crystals, or a combination of both make up clouds. A circulation of air moves up, expands, and cools when it rises upward due to rising temperature. When the water vapor reaches the saturation point, cooling might proceed until clouds are formed. A dust particle nucleus is where the condensation occurs. Each water molecule is tiny and floats in the atmosphere. The droplets don't start falling as rain until they combine to form a single drop with enough mass to overcome the air's resistance. As a result, clouds are viewed as crucial and reliable weather forecasting tools.

1.2 Humidity

Humidity is the amount of water vapor in the air. This is produced by the evaporation of water from marshes, lakes, rivers, and other bodies of water. Maximum water vapor concentration is determined by the air temperature. Absolute humidity, mixing ratio/humidity ratio, relative humidity, and specific humidity are the four methods of expressing humidity, [13], [14]. Absolute humidity refers to the amount of water (MW) in a volume of air (Va). However, any mass unit and volume unit may be employed. The following equation 1 represents vapor density or absolute humidity:

$$AH = \frac{m_w}{V_a} \quad (1)$$

However, even though the volume of water remains unchanged, absolute humidity changes as air pressure varies. It is difficult to determine its worth given its makeup. Using kilograms of water vapor (mw) to kilograms of dry air (md) at a certain pressure, the humidity mixing ratio is expressed, [15]. Moisture content and moisture content are alternative words for mixing and humidity ratio. Since it is unaffected by temperature unless the air cools below the dew point, the humidity ratio is a typical axis on psychometric charts and a useful number for psychometric calculations. Equation 2 gives the expression for this ratio as:

$$RH = \frac{P(H_2O)}{P^*(H_2O)} \times 100\% \quad (2)$$

where $P(H_2O)$ is the partial pressure of water vvaporin the gas mixture, $P^*(H_2O)$ is the saturated vapor pressure of water at the temperature of the gas mixture and RH is the relative humidity of the gas mixture.

The most commonly used method of expressing humidity is relative humidity since it is both simple to measure and maintains a consistent value with changes in atmospheric pressure due to water vapor in the air. The ratio of dry air plus water vapor in a given volume of air is known as specific humidity. Equation (3) defines it as the weight of water vapor (m_w) divided by the weight of air (m_a).

$$SH = \frac{Nw}{Na_a} \quad (3)$$

1.3 Rainfall

When it comes to weather patterns, rainfall is a significant climatic variable that can help plan water resources, agricultural productivity, and other aspects of a region's economy, [16]. Changing rainfall patterns is one of the many implications of climate change, which is a hot topic among scientists and academics around the world. There is a direct link between Nigeria's population and economy and its climate-sensitive activities, such as rain-fed agriculture, and extreme weather events, such as drought and floodwaters, have a significant impact on both. Understanding current and historical patterns and variations is essential to understanding their future growth, particularly in agricultural and hydrological areas, [17]. Climate change is a worldwide problem, and developing countries, particularly those in Africa, will bear the brunt of its effects. As a result of poverty and limited technological progress, farmers in Africa are unable to adapt to changing weather conditions and hence lack the ability to cultivate crops at a high level. Hence, climate change is expected to reduce food yields in Africa by 10 to 20 percent by 2050 or perhaps more, [17].

1.4 Study Area

The selected area (Lagos) for this study is located under the topical savannah climatic zones in the country. Table 1 presents the geographical information of the study area in Nigeria.

2 Research Methodology

11 years' worth of daily weather data (2011-2021), were gathered for this study from Visual Crossing, a leading provider of meteorological data and enterprise analytic tools to data scientists, business analysts, professionals, and academics, whose objective has been to provide analysts and data consumers with the tools they need to use trustworthy, readily available data to make better decisions ever since it was founded in 2003. These weather data (cloud cover, humidity, and rainfall) were then analyzed on a monthly and seasonal basis using the linear regression model on Microsoft Excel to determine the trends they exhibit. The obtained results were further confirmed using the Pearson product-moment correlation coefficient, known as the Pearson correlation coefficient, indicated by the letter ‘r’. This value measures the strength of a linear relationship between different

variables. The Pearson correlation coefficient, or r, measures how far all of these data points are off the line of best fit that a Pearson product-moment correlation attempts to build across the data of two variables (i.e., how well the data points fit this new model).

Table 1. The Geographical Information of Lagos, Nigeria

Station	Geo-Political Region	Climatic Zone	Geographical Coordinates (Lat & Long)	Landmass (Km²)
Lagos	South-West (SW)	Tropical savannah climate	6.4541°N & 3.3947°E	1,171

2.1 Establishment of Correlation

The strength and direction of a linear relationship between two random variables are described using a statistical concept called correlation, which is often expressed as a correlation coefficient. For various circumstances, different coefficients are utilized. The most often used is the Pearson product-moment correlation coefficient, which is calculated by dividing the variance of two parameters by the sum of their standard deviations. The correlation coefficient, given by equation 4, also known as "r", has a range of -1 to +1. The "r" has the following mathematical formula:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad (4)$$

where r is the correlation coefficient, x_i represents the values of the x-variable in a sample, $\bar{x}$ represents the mean of the values of the x-variable, y_i is the values of the y-variable in a sample and $\bar{y}$ represents the mean of the values of the y-variable.

With all measured values on the same line and Y increasing with X, a value of 1 indicates that the relationship is precisely and positively described by a linear equation. When the value is -1, all the data points are shown to be on a single line, but Y increases as X decreases. If the value is 0, there is no need for a linear model because there is no linear relationship between the variables. To determine the relationship between cloud cover and other meteorological factors, the same location and period of data have first been identified. The relationship is found by taking the average of the monthly data from 2011 to 2021.

3 Results and Discussion

This section presents the results and discussion of the analysis of meteorological parameters (cloud cover, humidity and rainfall) in the study area.

3.1 Monthly Variations of Cloud Cover and Humidity

From the data analysis in Figure 1, it can be seen that the cloud cover increases starting from February to October, and then starts declining as the dry season commences. However, there was a change in this trend in the year 2017, where there was a decrease in the percentage of cloud cover recorded in April and May compared to that recorded in March, which is contrary to the trend observed in other years. Also, in the year 2017, it was observed that the percentage of cloud cover recorded in October was higher than that of September, which is also contrary to the trend observed in other years. Humidity, on the other hand, maintains a higher percentage throughout the year, and this pattern is observed in all the years under consideration, thus increasing from May to October. This high percentage can be attributed to the location of the study area, which is along the coast and is also at a lower latitude. The minimum cloud cover and humidity percentage were recorded to be 27.24% in January 2011 and 61.29% in December 2015, respectively. The maximum cloud cover and humidity percentage were recorded to be 74.39% in March 2017 and 88.99% in October 2019, respectively. In conclusion, it is important to note that both cloud cover and humidity maintain a direct proportionality to each other in the sense that as one increases, so does the other and vice versa.

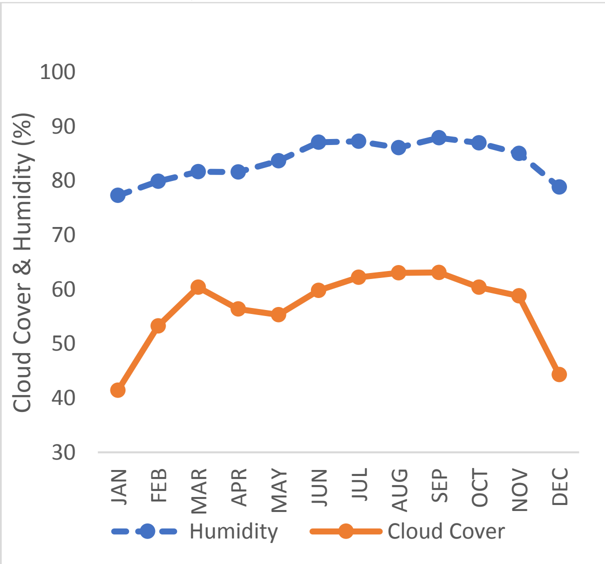

Fig. 1: Monthly variation of cloud cover and humidity (2011-2021)

3.2 Monthly Variation of Rainfall

Rainfall in the study area exhibits double maxima most of the time, with a peak period in June-July and September-October as shown in Figure 2. However, some of the years under consideration showed contrasting patterns, with some having peaks in May and others having three peaks as well. It is also observed in the study area that there is a short dry season experienced in August, and this dry period is commonly referred to as the "August break," which is a result of a halt in the torrential rain that visits mostly the southern region of the country due to the tropical climate. The double maxima phenomenon exhibited in the study area is a characteristic of rainfall in southern Nigeria, [18]. This is also similar to the observation made by [18] that the rainfall pattern below latitude 100 N is bimodal, having a primary peak in June-July and another secondary peak in September, with little dry season in August as a result of the absence of the African Easterly Jet. Rainfall in this study area is virtually throughout the year and the reason for this can be attributed to the fact that it is located along the coast and is also at a lower latitude. The mean monthly rainfall throughout the years under consideration ranged between 0 mm to 456.6 mm, with the peak rainfall recorded to be 456.5 mm in October 2019, while the minimum rainfall was recorded to be 0 mm in different years under consideration. As earlier observed by [18], the increasing amount of rainfall in the coastal cities may be partly responsible for the increase in flood events devastating the lives and properties of people based in the study area.

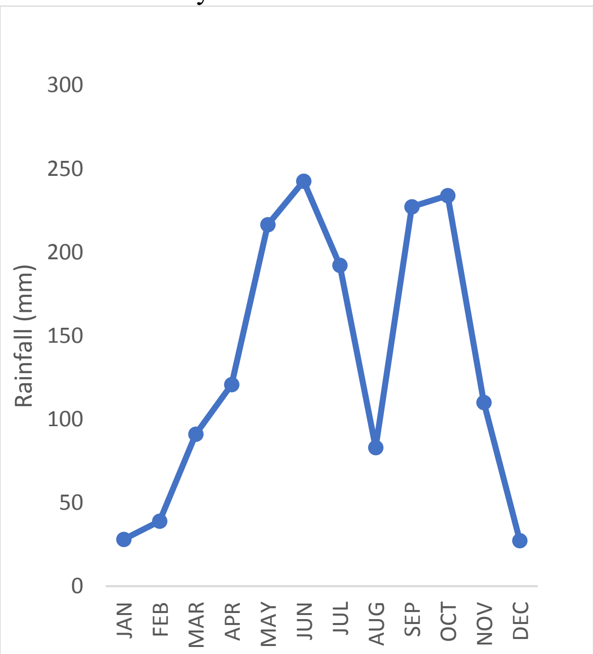

Fig. 2: Monthly variation of rainfall (2011-2021)

3.3 Seasonal Variation of Cloud Cover and Humidity

From the data analysis in Figure 3, it can be seen that there is an increase in the percentage of cloud cover starting from the late dry season up until the late wet season before it starts decreasing towards the early dry season. However, some years show a contrasting difference to this observed pattern. It was observed in the years 2013, 2014, and 2020 that the percentage of cloud cover increases throughout the year regardless of the season. In the same vein, the percentage of cloud cover decreases beginning with the early wet season in 2015 and 2017. The same pattern as observed for cloud cover can be said to be true for that of humidity also, since from the correlation coefficient obtained, cloud cover is directly proportional to humidity. Nevertheless, some years, such as 2012, 2016, 2018 & 2021, also show a contrasting difference to this observed pattern. It was observed that the percentage of humidity increases throughout the year regardless of the season. In conclusion, the percentage of humidity and cloud cover starts increasing in the late dry season and decreases towards the early dry season as shown in Figure 3. It was also discovered that the percentages of cloud cover and humidity are directly proportional. This means that an increase in the percentage of cloud cover leads to an increase in the percentage of humidity and vice versa.

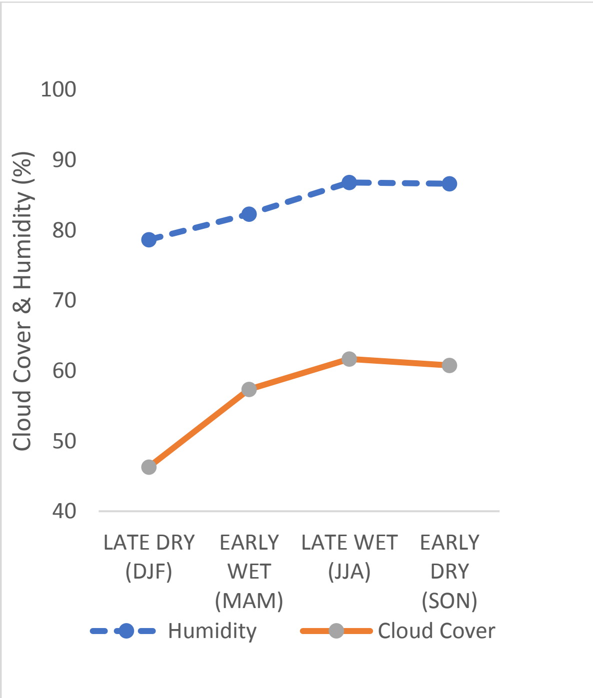

Fig. 3: Seasonal variation of cloud cover and humidity (2011-2021)

3.4 Seasonal Variation of Rainfall

In Figure 4, it can be seen that there is an increase in the amount of rainfall starting from the late dry wet season up until the late wet season before it starts decreasing towards the early dry season. However, some years, such as 2012, 2014, 2016, 2019, and 2021, show a contrasting trend to the normal pattern observed. It was recorded in these years that there was a surge in the amount of rainfall, and this is evident in the early dry season where the trend is meant to curve downwards but instead keeps increasing. This contrasting pattern led to devastating flooding, claiming lives and properties, [19]. The peak amount of rainfall was recorded to be 267.3 mm in the early dry season of 2019, while the least amount of rainfall was recorded to be 10.23 mm in the late dry season of 2020. It is important to note that rainfall in this study area is virtually throughout the year, ranging from the late dry season through to the early dry season as shown in Figure 4, and the reason for this can be attributed to the fact that the study area is located along the coast and is also at a lower latitude.

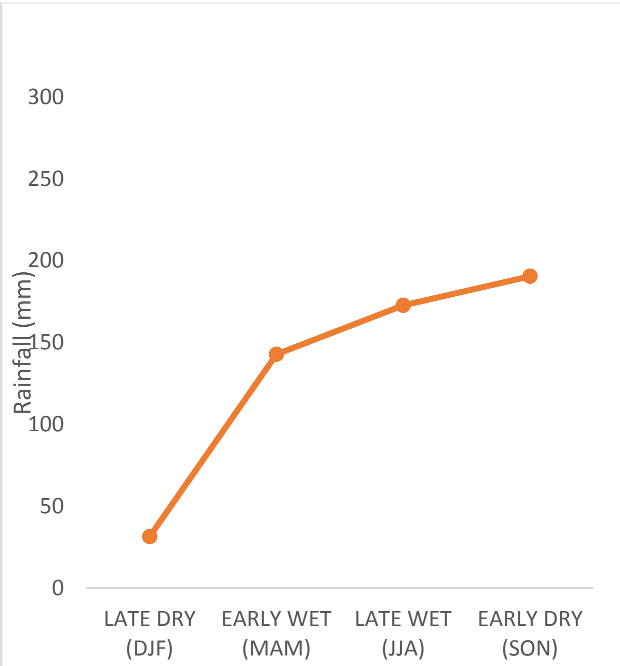

Fig. 4: Seasonal variation of rainfall (2011-2021)

3.5 Correlation between Cloud Cover and Other Meteorological Variables

Table 2 shows the range of values for small correlation, medium correlation, and large correlation. The correlation coefficients between cloud cover and other meteorological variables are displayed in Table 3. The correlation coefficient (r) between cloud cover and other meteorological data can be classified into three groups.

Table 2. Categories of Correlation

Correlation	Negative	Positive
Small	0.3 to 0.1	0.1 to 0.3
Medium	0.5 to 0.3	0.3 to 0.5
Large	1.0 to 0.5	0.5 to 1.0

3.5.1 Correlation between Cloud Cover and Humidity

The outcomes of the analysis for the average of the years under review are displayed in Figure 5, and it is based on the association between cloud cover and humidity. The analysis's findings demonstrated that there is a strong positive correlation between the two meteorological parameters for every year that was considered, except the years 2014 and 2021, which had small positive r values and medium positive r values, respectively, when comparing the calculated correlation coefficient with the correlation categories provided. By contrasting the calculated correlation coefficients with the given correlation categories, this was discovered, and it is evident that there has been a precise association between cloud cover and humidity in the research area over the years analyzed when the trend of the environmental parameters from the linear regression is compared to the correlation value.

Table 3. Correlation between Cloud Cover and Other Climatic Parameters

Year	r	
	Humidity (%)	Rainfall $(\frac{mm}{day})$
2011	0.90	0.75
2012	0.86	0.53
2013	0.82	0.31
2014	0.42	0.25
2015	0.78	0.47
2016	0.91	0.66
2017	0.64	0.26
2018	0.88	0.60
2019	0.69	0.55
2020	0.91	0.51
2021	0.25	0.04
AVG	0.88	0.65

3.5.2 Correlation between Cloud Cover and Rainfall

The outcomes of the analysis of the average of the years under review are displayed in Figure 6 and it is based on the correlation between cloud cover and humidity. Based on the findings of the investigation, it is clear that the degree of positive correlation that exists between the two meteorological parameters across the years that were taken into account and which are presented in Table 3 falls somewhere in the middle of the small and medium positive correlation coefficients presented in Table 2. According to this correlation, the relationship between cloud cover and rainfall is not an exact one. There is, therefore, no disputing the link between an increase in the proportion of cloud cover and an increase in the quantity of precipitation that occurs. One can notice that this is a general tendency.

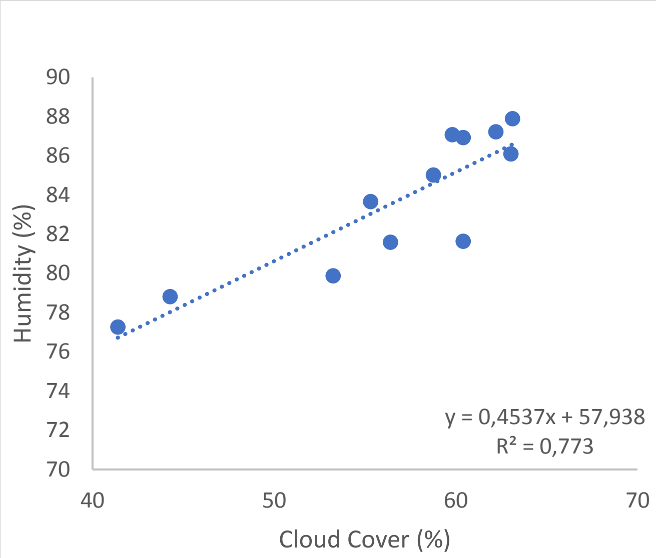

Fig. 5: Correlation between cloud cover and humidity (2011-2021)

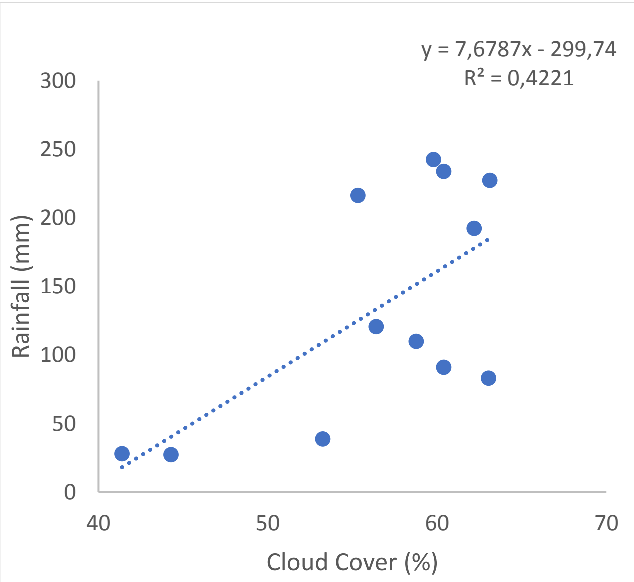

Fig. 6: Correlation between cloud cover and rainfall (2011-2021)

4 Conclusion

The basis of this work is the relationship between changes in relative humidity and rainfall with cloud cover in space and time. It is also possible to use the Pearson Product Moment Correlation Coefficient to ascertain the relationship between the cloud cover and the other meteorological information. The findings of this study support the following assertions: - From March to October, Lagos experiences a significant amount of cloud cover, with September being the highest. Approximately 65% of the sky is cloudy during September. From December to February, there is a minimum amount of cloud cover, with the maximum in January. Only a small portion of the sky is cloud-covered in January and December, which is slightly more than 40%. The peak month for cloud formation is September, but the emergence of clouds can occur as early as February. In addition, cloud formation begins to decline in October, and it is barely noticeable in January. Compared to the dry season, cloud formation is higher during the wet season. The average relative humidity in Lagos is 83.5 percent all year, with the highest percentages recorded between June and October. September experiences the highest relative humidity, while January experiences the lowest. Throughout the year, the relative humidity in Lagos ranges between 76 and 87 percent. On average, about 1611.30 mm of precipitation falls on Lagos each year. During the late wet season, there is a high rate of precipitation in June, September, and October, with June having the greatest rate. December through February had the lowest precipitation rates. In general, the precipitation rate decreases from November to February and then begins to increase from March to July. However, the rainfall rate decreases in August, which represents a brief dry period during the wet season and the end of the heavy downpours that mostly affect the southern region. The maximum duration of rainfall in the study area is eight months while the minimum is four months, the peak rainfall was observed in June, while the highest rainfall rate was recorded in the year 2019. Cloud cover, humidity, and rainfall in Lagos have a high, positive correlation coefficient (r). This indicates that as humidity increases, the percentage of cloud cover also increases. As the amount of cloud cover in the sky increases, the rainfall rate likewise increases. To put it another way, cloud cover, humidity, and rainfall are directly proportional.

The study recommends the following: - As a step toward improving people's ability to adjust to changing conditions, it is important to launch awareness campaigns that educate the public about recent shifts in the amount of rainfall. This is significant because the population's capacity to properly respond to increasing rainfall will be largely decided by the quality of information that is readily available to them and the ease with which they can acquire it. It is important for government policies that affect agriculture, water resources development, and other associated sectors to take into account potential solutions to the problem of a rise in the amount of rainfall that has occurred in recent years according to this study. Additional studies could be carried out in several different cities around the country.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflict of interest to declare.