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Climate Trend Analysis Using Mann-Kendall and Sen's Slope Estimator Tests in Central Luzon, Philippines

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Abstract

Climate change is one of the most pressing global challenges, affecting weather patterns, ecosystems, and human livelihoods. The climatological factors of rainfall, temperature, relative humidity, and wind speed were analyzed to determine the climate trend over the last 41 years in Central Luzon, Philippines. The non-parametric Mann-Kendall (MK) and Sen's Slope Estimator (SSE) tests were applied to annual and monthly datasets from 1980 to 2021 across seven synoptic weather stations in the region. Results indicate a significant upward trend in annual temperature at all stations, with the most pronounced increases occurring in May, November, and December. This suggests that Central Luzon will experience continued warming in the coming years. Relative humidity exhibited a declining trend annually across the region and in all months in Casiguran. Wind speed showed a downward trend in Baler Radar, Cabanatuan, and Iba stations, while Casiguran experienced an upward trend. Although annual rainfall did not display a significant overall trend, an increasing pattern was observed in December in Casiguran, while May rainfall declined in Cubi Point. These findings indicate that climate change is already affecting the region, potentially leading to extreme weather events such as droughts and heatwaves that could severely impact the agricultural sector. Further studies are necessary to investigate the underlying causes of rising temperatures and declining humidity, as well as their broader implications for local and regional climate systems.

Keywords: Climate change, Trend analysis, Mann-Kendall, Sen's Slope Estimator

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1. Introduction

The climate of a region is shaped by long-term weather patterns, which can vary hourly, daily, monthly, or annually. To define climate, meteorologists typically analyze weather data over a period of at least 30 years. The Earth's climate is diverse, ranging from extreme heat to frequent rainfall and prolonged winters in snow-covered regions [1]. Climate change refers to significant shifts in average weather conditions over several decades or more, leading to warmer, wetter, or drier environments. The key distinction between climate change and natural weather variability lies in long-term trends [2]. Trend analysis in meteorology plays a crucial role in predicting future weather conditions by examining past and present patterns. Understanding these trends enhances meteorologists' ability to forecast extreme weather events such as storms, heatwaves, droughts, and heavy rainfall.

Trend analysis is a method used to assess how and why certain variables have changed over time and how they may continue to change in the future [3]. In analyzing the climate trends in Central Luzon, Philippines, the non-parametric Sen's Slope Estimator (SSE) and Mann-Kendall (MK) tests were employed

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to determine the presence of positive or negative trends in climate data, along with their statistical significance and degree of variation [4]. The MK test evaluates differences between consecutive data points, identifying whether a consistent upward or downward trend exists. Meanwhile, the SSE test quantifies the magnitude of a trend over a given period, providing a clearer picture of the rate of change.

A similar study analyzing twelve rainfall stations in Mempawah and Kubu Raya, Indonesia, identified trends in annual precipitation using the Mann-Kendall (MK) test and Sen's Slope Estimator (SSE). The findings suggested that increased rainfall could contribute to flooding in these low-lying coastal regions, indicating climate change in West Kalimantan [5]. Another study applied the MK and SSE tests to examine ambient temperature changes in the Calabar region of southern Nigeria from 1998 to 2018, revealing a consistent rise in both maximum and average temperatures [6]. In Iraq’s Sinjar district, three statistical methods Sen’s Slope Estimator, the non-parametric MK test, and linear regression were used to analyze 70 years of precipitation data (1940–2010). The results showed a generally consistent trend across all months, except for April, which exhibited a negative linear regression [7]. Similarly, an analysis of spatial and temporal precipitation patterns in Senegal, using data from 22 stations between 1940 and 2013, found a decreasing trend in yearly rainfall at 21 locations. Despite an increase in annual rainfall from 1984 to 2013, the overall trend over the 74-year period indicated a significant decline, except in a few localized areas in the north, east, south, and west [8]. In Ethiopia, gridded annual temperature and precipitation data from 1983 to 2008, provided by the National Meteorology Agency (NMA), offered insight into farmers' perceptions of climate variability. The MK and SSE tests revealed a positive trend in annual temperatures, increasing by 0.02°C per year in lowland areas and 0.04°C per year in highland regions [9].

According to the Department of Science and Technology – Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA), the country’s central weather bureau responsible for providing scientific knowledge on natural calamities, the Philippines has a tropical climate influenced by the surrounding seas. It is characterized by consistently warm temperatures, high humidity, and significant rainfall. The country’s climate shares many similarities with those of Central American nations. Key factors affecting weather and climate in the Philippines include temperature, humidity, wind speed, and rainfall.

The Central Luzon region, or Region III, in the Philippines is composed of elevated mountains, both active and inactive volcanoes, fertile agricultural lands, and naturally formed ports. Strategically located in Asia, it is one of the fastest-growing regions in the country. Often referred to as the "Central Plains of Luzon," it is the oldest active sector in the lowlands and consists of seven provinces. Central Luzon is also known as the "Rice Granary of the Philippines," producing one-third of the nation’s total rice supply. However, in recent years, climate change has significantly impacted food quality and accessibility. Rising temperatures, shifts in rainfall patterns, increased frequency of extreme weather events, and declining water availability have all contributed to reduced agricultural productivity. Despite these challenges, no comprehensive climate trend analysis has been conducted in Central Luzon. This study aims to fill that gap, serving as a foundation for further climate trend analyses in other regions of the Philippines and across Southeast Asia, ultimately providing a broader understanding of climate change and its effects.

2. Methodology

2.1 Study Area

This study focused on Central Luzon, Philippines, located at 15°24’10.80” north latitude and 121°00’28.80” east longitude. The region spans approximately 180 km from west to east and 170 km from north to south. According to the Department of Science and Technology – Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA), Central Luzon has seven synoptic weather stations situated in the following locations: (1) Iba, Zambales; (2) Cubi Point, Olongapo City, Zambales; (3) Clark, Pampanga; (4) Cabanatuan, Nueva Ecija; (5) Baler (Radar), Aurora; (6) CLSU, Nueva Ecija; and (7) Casiguran, Aurora.

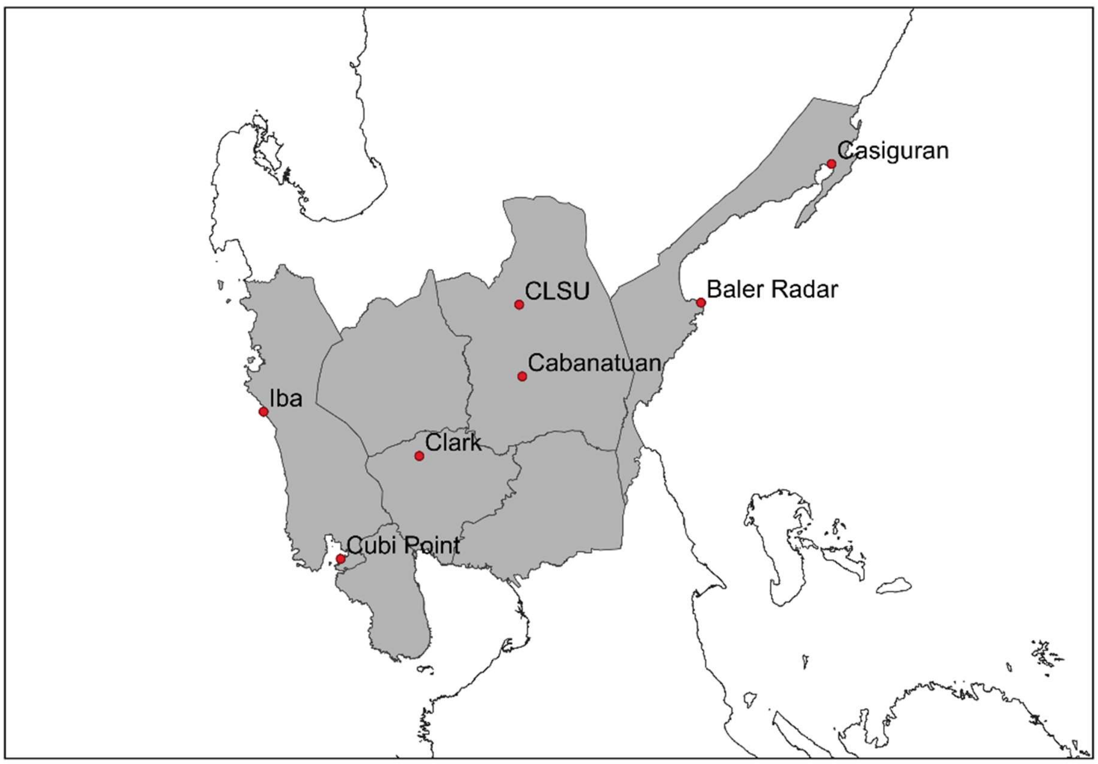

Figure 1. Location of the synoptic stations in Central Luzon region, Philippines

2.2 Data

The dataset spans from 1980 to 2021 for all seven synoptic weather stations in Central Luzon, Philippines, with their geographical details presented in Table 1. However, data from the CLSU station is available only for the years 2019–2021. As a result, the Mann-Kendall (MK) and Sen’s Slope Estimator (SSE) tests could not be applied, as these methods require a minimum of 8 to 10 years of data for reliable analysis.

Table 1. Climatological synoptic stations of DOST-PAG-ASA at Central Luzon, Philippines

Station	Province	Latitude	Longitude	Elevation	Available Data
Baler Radar	Aurora	15.748809 N	121.632028 E	173 m	1995-2021
Cabanatuan	Nueva Ecija	15.470387 N	120.951143 E	32 m	1991-2018
Casiguran	Aurora	16.265083 N	122.128888 E	4 m	1980-2021
Clark	Pampanga	15.1717 N	120.5616667 E	151.564 m	1997-2021
CLSU	Nueva Ecija	15.7358556 N	120.93678056 E	7.6 m	2019-2021
Cubi Point	Zambales	14.787679 N	120.266619 E	19.087 m	1994-2021
Iba	Zambales	15.328408 N	119.965661 E	5.538 m	1980-2021

Data Source. Climatology and Agrometeorology Division, DOST-PAG-ASA (2022)

2.3.1 Mann-Kendall Test

The Mann-Kendall (MK) trend test is one of the more recognizable significant analytical procedures frequently applied for identifying the pattern in a climatological and hydrologic time series [10]. It is a trend which is non-parametric and does not need data that is normally distributed. Long-term trends in the analysis of hydrologic and climate series have frequently used it. For the time series x_i to x_n, the MK test statistics is measured as follows:

$$S = \sum_{i=1}^{n=1} \sum_{j=i+1}^{n} \mathrm{sign}(x_j - x_i) \tag{1}$$

$$\mathrm{sign}(x_j - x_i) = \begin{cases} +1 & (x_j - x_i) > 0 \\ 0 & (x_j - x_i) = 0 \\ -1 & (x_j - x_i) < 0 \end{cases} \tag{2}$$

A positive trend is shown by an upward S value, whereas a negative trend is indicated by a downward value. Ties within the formula are situations where two or more findings have the same value. To determine the Z value, the variance is evaluated. Variance (S) is calculated as:

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \tag{3}$$

The overall number of the ties for the i value is presented by t_i and the total number of tied values is represented by m. When n is greater than ten, the statistic test Z approximates the typical normal distribution:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var(S)}}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var(S)}}} & S < 0 \end{cases} \tag{4}$$

A positive Z value indicates an expanding trend, whereas a negative Z value indicates a decreasing trend.

2.3.2 Sen's Slope Estimator

Sen's Slope Estimator (SSE) was employed in calculating the slope of the n sets of data points. The trend, which serves as a measurement of the time change in this test, is expected to be linear. Sen's slope possesses an advantage over linear regression in that the assessment remains unaffected by the existence of anomalies and inaccuracies in data [5]. The magnitude of trend Q is calculated as follows:

$$Q_i = \frac{x_j - x_i}{j - i} \tag{5}$$

where x_j and x_i are the current data values of j and i ($j > i$), respectively. Using the Q, the null hypothesis that the slope of the relationship between two variables is equal to zero was analyzed. The Q value is obtained by taking the average of all pairwise slopes between the sample's data points.

3. Results and Discussion

3.1 Annual climate trend analysis in Central Luzon, Philippines

The results of the Mann-Kendall (MK) and Sen's Slope Estimator (SSE) tests for each climate variable, rainfall (mm), temperature (°C), relative humidity (%), and wind speed (m/s), are presented in Table 2. The MK analysis of annual rainfall showed no significant trend across all synoptic stations in Central Luzon, as the values did not meet the 95% confidence level. This indicates that annual rainfall in the region has remained relatively stable over the past 41 years. This finding aligns with PAGASA's report, which states that statistical analyses do not show significant changes in extreme daily rainfall across the country.

In contrast, a highly significant increasing trend in temperature was observed at the Baler Radar, Cabanatuan, Clark, Cubi Point, and Iba stations. The province of Pampanga experienced an annual temperature increase of 0.0622°C per year from 1997 to 2021. Meanwhile, in Zambales, temperature increases of 0.0263°C and 0.0321°C per year were recorded at the Cubi Point and Iba stations, respectively. Nueva Ecija also experienced a steady annual temperature increase of 0.0206°C over the past 38 years.

The data from the Casiguran station also exhibited a significant trend, indicating that the province of Aurora experienced an annual temperature increase of 0.0237°C at Baler Radar and 0.0154°C at Casiguran station. The average temperature across Central Luzon showed a highly significant trend, with a yearly increase of 0.0257°C. This finding aligns with PAGASA's report, which states that the country's annual temperature has increased over the past 60 years by 0.36°C during the daytime and 1.0°C at night. Additionally, PAGASA has observed an increase in extreme hot days and a decrease in cooler nights compared to the 1961–1990 baseline, with most of these trends being statistically significant [11].

Relative humidity in Central Luzon showed mixed results. While the regional average indicated a highly significant decreasing trend, this trend was not consistently observed across all stations. The relative humidity data from Baler Radar, Cabanatuan, Cubi Point, and Iba stations were not significant at the 95% confidence level. However, Casiguran station in Aurora recorded a highly significant annual decrease of 0.1308% from 1980 to 2021. A similar trend was observed at

Clark station in Pampanga, where relative humidity declined by 0.1735% per year from 1997 to 2021. Overall, Central Luzon experienced an annual decrease of 0.1278% in relative humidity from 1980 to 2021.

Table 2. Annual climate trends in Central Luzon, Philippines

Station [a]	Test [b]	Climate Factors [c]			
		Rainfall (in mm)	**Temperature** (in degree Celsius)	**Relative Humidity** (in %)	**Wind Speed** (in m/s)
Baler Radar	MK	0.1668	2.8769*	1.4593	-4.2111*
	SSE	0.0072	0.0237 ↑	0.0793	-0.0383 ↓
Cabanatuan	MK	0.2439	3.6578*	0.2814	-2.5511*
	SSE	0.0056	0.0206 ↑	0.0320	-0.0194 ↓*
Casiguran	MK	1.6039	2.2325*	-4.5300*	5.0611*
	SSE	0.0499	0.0154 ↑	-0.1308 ↓	0.0235 ↑
Clark	MK	-0.7240	3.7134*	-3.2463*	-0.5372
	SSE	-0.0253	0.0622 ↑	-0.1735 ↓	-0.0056
Cubi Point	MK	0.0988	3.6550*	0.0000	-0.4939
	SSE	0.0068	0.0263 ↑	-0.0018	-0.0028
Iba	MK	-0.6502	4.8335*	0.8887	-6.7409*
	SSE	-0.0148	0.0321 ↑	0.0365	-0.0325 ↓
Central Luzon	MK	-1.2138	4.8335*	-5.7438*	-0.2384
	SSE	-0.0279	0.0257 ↑	-0.1278 ↓	-0.0009

[a] CLSU synoptic station was not solved by MK and SSE since the available data are only 3 years (minimum of 10 years was required) but was included in the average data of Central Luzon.
[b] MK = Mann-Kendall test indicates if there is an increasing or decreasing trend over time and SSE = Sen's Slope Estimator test indicates the magnitude of change of rainfall, temperature, relative humidity and wind speed.
[c] SSE with ↑ indicates an increasing trend while ↓ indicates a decreasing trend.
*Significant at 95% confidence level.

Regarding wind speed, no significant trend was detected at Clark and Cubi Point stations, nor for Central Luzon as a whole. However, Baler Radar, Casiguran, Iba, and Cabanatuan stations showed highly significant trends at the 95% confidence level. The province of Aurora experienced an annual wind speed decrease of 0.0383 m/s at Baler Radar station, while Casiguran station in the same province exhibited an increasing trend of 0.0235 m/s per year. Additionally, Zambales recorded a decreasing wind speed trend of 0.0325 m/s annually at Iba station.

3.2 Monthly climate trend analysis in Central Luzon, Philippines

3.2.1 Monthly rainfall trend analysis

The results of the Mann-Kendall (MK) test for monthly rainfall at the Baler Radar, Cabanatuan, Clark, Iba stations, and the overall Central Luzon region indicated no significant trend from January to December. This is because the MK values for these stations did not meet the 95% confidence level. However, a highly significant upward trend was detected at the Casiguran station in December, suggesting that rainfall in this month has been increasing at a rate of 0.3289 mm per year in the province of Aurora.

Additionally, a highly significant trend was observed at the Cubi Point station in May, indicating a decreasing monthly rainfall trend of 0.7003 mm per year in the province of Zambales. The scattered changes in rainfall patterns during May, June, July, and September, which show a decreasing trend, may be partially explained by their alignment with the country's rainy season [12].

Table 3.1. Monthly rainfall trends in Central Luzon, Philippines

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baler Radar	■	■	■	■	■	■	■	■	■	■	■	■
Cabanatuan	■	■	■	■	■	■	■	■	■	■	■	■
Casiguran	■	■	■	■	■	■	■	■	■	■	■	▲
Clark	■	■	■	■	■	■	■	■	■	■	■	■
Cubi Point	■	■	■	■	▼	■	■	■	■	■	■	■
Iba	■	■	■	■	■	■	■	■	■	■	■	■
Central Luzon	■	■	■	■	■	■	■	■	■	■	■	■

Note. Red triangle indicates a positive increasing trend; Green triangle indicates a negative decreasing trend; Gray square indicates no trend.

3.2.2. Monthly temperature trend analysis

The trend analysis of temperature at the Baler Radar station showed a significant increasing trend in the months of May, June, August, and December. Similarly, data from the Cabanatuan station revealed a significant upward trend in temperature during certain months. According to PAGASA, the highest recorded temperature in Cabanatuan reached 39.9°C in April 1961. This extreme aligns with the observed increasing temperature trend in Cabanatuan during April from 1991 to 2018.

In Pampanga, the Clark station exhibited a rising temperature trend from February to September and again from November to December. Additionally, the Casiguran station recorded a significant temperature increase in January, November, and December.

Table 3.1. Monthly Temperature Trends using MK and SSE Tests in Central Luzon, Philippines

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baler Radar	■	■	■	■	▲	▲	■	▲	■	■	■	▲
Cabanatuan	▲	■	■	▲	▲	■	■	■	■	■	▲	▲
Casiguran	▲	■	■	■	■	■	■	■	■	■	▲	▲
Clark	■	▲	▲	▲	▲	▲	▲	▲	▲	■	▲	▲
Cubi Point	■	■	■	■	▲	■	■	■	▲	■	▲	▲
Iba	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
Central Luzon	▲	▲	▲	▲	▲	▲	■	■	▲	▲	▲	▲

Note. Red triangle indicates a positive increasing trend; Green triangle indicates a negative decreasing trend; Gray square indicates no trend.

Meanwhile, a highly significant increasing temperature trend was observed in the months of May, September, November, and December at the Cubi Point station, while the Iba station exhibited a rising trend in temperature across all months. These results indicate that the monthly temperature in Zambales has been increasing from 1980 to 2021.

The average monthly temperature in Central Luzon also showed a highly significant upward trend in all months except for July and August. A pronounced warming trend was particularly evident from January to May and from September to December. May was recorded as the warmest month, with a mean temperature of 28.3°C, influenced by both seasonal and meteorological factors. This period marks the transition from the dry season (January to May) to the onset of the Southwest Monsoon (Habagat).

According to PAGASA, this warming trend aligns with national projections based on data from meteorological stations across the Philippines. Comparatively, all regions in the country are expected to become warmer, with mean temperatures projected to rise by 0.9 to 1.1°C by 2020 and by 1.8 to 2.2°C by 2050. The most significant temperature increases are expected during the summer months.

3.2.3. Monthly relative humidity trend analysis

The stations of Baler Radar, Cabanatuan, and Cubi Point showed no significant trends in relative humidity across all months, as presented in Table 3.3. However, the Casiguran station in Aurora exhibited a highly significant downward trend in monthly relative humidity for all months. Additionally, the Clark station in Pampanga recorded a highly significant decreasing trend in May and September, with relative humidity declining by 0.3263% per year in May and 0.2764% per year in September.

Table 3.3. Monthly relative humidity trends in Central Luzon, Philippines

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baler Radar	■	■	■	■	■	■	■	■	■	■	■	■
Cabanatuan	■	■	■	■	■	■	■	■	■	■	■	■
Casiguran	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
Clark	■	■	■	■	▼	■	■	■	▼	■	■	■
Cubi Point	■	■	■	■	■	■	■	■	■	■	■	■
Iba	■	■	■	■	■	■	■	■	■	■	■	▲
Central Luzon	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼

Note. Red triangle indicates a positive increasing trend; Green triangle indicates a negative decreasing trend; Gray square indicates no trend.

In the province of Zambales, the Iba station recorded a significant increasing trend in relative humidity only for the month of December. Notably, in December 1967, the station observed a climatological extreme with a relative humidity level of 1019 millibars. This historical anomaly may support the trend analysis, which indicates an increasing trend at the station over the data span of 1980–2021. Meanwhile, the average monthly relative humidity in the Central Luzon region exhibited a highly significant decreasing trend across all months from 1980 to 2021.

3.2.4. Monthly wind speed trend analysis

Table 3.4 indicates a significant decreasing trend in wind speed at the Baler Radar station during the months of January to May, as well as in September and November. Historical climatological data show that wind speeds were lowest from January to March, aligning with the trend analysis from 1980 to 2021. The recorded wind speed extremes for these months were 17 m/s (WNW) in January, 15 m/s (E) in February, and 18 m/s (NE) in March. Similarly, the Cabanatuan station exhibited a significant decreasing trend in wind speed during January to March, May to July, November, and December. According to PAGASA, climatological extremes in wind speeds were recorded in Cabanatuan in November 1983, supporting the observed downward trend.

Table 3.4. Monthly wind speed trends in Central Luzon, Philippines

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baler Radar	▼	▼	▼	▼	▼	■	■	■	▼	■	▼	■
Cabanatuan	▼	▼	▼	■	▼	▼	▼	■	■	■	▼	▼
Casiguran	▲	▲	▲	▲	▲	▲	■	▲	▲	▲	▲	▲
Clark	■	■	■	■	■	■	■	■	■	■	■	■
Cubi Point	■	■	■	■	■	■	■	■	■	■	■	■
Iba	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
Central Luzon	▲	■	■	■	■	▼	■	■	■	■	■	■

Note. Red triangle indicates a positive increasing trend; Green triangle indicates a negative decreasing trend; Gray square indicates no trend.

In contrast, the results revealed a significant increasing wind speed trend at the Casiguran station in the province of Aurora. Wind speeds showed an upward trend at a 95% confidence level in all months except for July. However, the Clark and Cubi Point stations exhibited no significant trends from January to December, as the MK test values were not statistically significant at the 95% confidence level.

Meanwhile, the Iba station recorded a significant decreasing trend in wind speed across all months at the 95% confidence level. The lowest wind speeds at Iba, Zambales were recorded in March and December, specifically in 1994 and 1980, with values of 16 m/s (E) and 18 m/s (SE), respectively, according to PAGASA's Climatological Extremes.

Additionally, for the entire Central Luzon region, a significant wind speed trend was detected only in January and June. The results indicate an increasing trend of 0.0109 m/s per year in January, while June showed a decreasing trend of 0.0089 m/s per year. No significant wind speed trends were observed in the remaining months for the Central Luzon region.

4. Conclusion

Over the span of 41 years, annual analysis of rainfall and wind speed shows no positive or negative trends in Central Luzon. However, there is a highly increasing significant temperature trend with an annual change of 0.0257 °C in the Central Luzon region and a significant decrease of 0.1278% per year of relative humidity, indicating that the region will experience a hotter climate in the coming years. The MK and SSE tests also show a significant decreasing rainfall trend in the month of May at Cubi Point and an increasing trend in December at Casiguran. These patterns may be influenced by the seasonal monsoons, as May marks the transition period leading to the Southwest Monsoon (*Habagat*), which typically brings warm, moist air and heavy rainfall, while December falls within the Northeast Monsoon (*Amihan*), which is generally associated with cooler temperatures and rainfall on the eastern portions of the country.

Moreover, in the months of May, November, and December, there is a significant increasing temperature trend in almost all stations. Meanwhile, a highly significant decreasing relative humidity trend was recorded in Casiguran and across Central Luzon in all months. A decreasing wind speed trend was detected in some months at the stations of Baler Radar, Cabanatuan, and Iba (all months), whereas an increasing wind speed trend is observed in Casiguran. These findings suggest that the monsoonal patterns, along with broader climatic changes, may be influencing long-term shifts in temperature, rainfall, humidity, and wind dynamics in Central Luzon.

In addition to the results of the study, the climate profile of Central Luzon was visualized and presented using Google Looker Studio, an online dynamic data visualization application, at https://bit.ly/Climate-Central-Luzon.

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