International Journal of Scientific Research and Engineering Development-– Volume 7 Issue 1, Jan-Feb 2024

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Analysis of the climate change trend in Nanjing from 1951 to 2020

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Abstract:

Climate is very important human life and direct effect on the Whole world's behaviors. From 1951 to 2020, I studied the trend of climate change in Nanjing, China. Temperature, precipitation, sunlight hour, and relative humidity are the analyzed factors. This study's content is mainly based on a trend analysis of climate change. The analysis is carried out in two directions. One of the most important aspects of the research is the annual climate change trend in Nanjing from 1951 to 2020. The key focus areas are the annual average temperature trend, the annual maximum temperature trend, the annual minimum temperature trend, the annual relative humidity trend, and the annual sunshine hour trend. The seasonal climate change trend in Nanjing from 1951 to 2020 is another research path. It attempted to demonstrate the significance of climate change by analyzing from 1951 to 2020 climate change data by using the XLSTAT software. Annual and seasonal climate factors were analyzed using Mann-Kendall (MK) trend test. Annual average temperature, average maximum temperature, and average minimum temperature trends increased and all the seasons (autumn, spring, summer, and winter) increased trend. The average annual relative humidity and all the seasonal graphs were the negative trends that mean relative humidity was decreased within the study period. The total annual precipitation trend was decreasing too. But when seasonal total precipitation autumn, summer, and winter were increased trend but the spring was decrease trend. Not only precipitation but also annual total sunshine hour was decrease trend. All seasons of the sunshine hour was decrease trend.

Keywords —**Temperature, Precipitation, Relative humidity, Sunshine hour, Trend analysis.**

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I. INTRODUCTION

A. *Purpose and significance of this study.*

Climate is measured over time but weather can change from day to day or year to year. For this reason, weather differs from climate. The climate of a place is determined by seasonal temperature, rainfall averages, relative humidity, sunshine hour, etc. Climates differ based on your location. Temperature and precipitation are the main factors of climate. Natural factors such as latitude, elevation, and the presence of ocean currents significantly influence the temperature of a region. Factors such as proximity to mountain ranges and prevailing winds influence the precipitation characteristics of a region.

Climate change is a long-term change in a place's temperature and usual weather patterns. Climate change may refer to a specific area or the entire world.As a result of climate change, weather patterns may become less predictable. Since predicted temperature and rainfall levels can no longer be depended upon, these unexpected weather patterns can make it difficult to sustain and grow crops in farming-dependent areas. Other destructive weather phenomena linked to climate change include more frequent and more severe hurricanes, flooding, downpours, and winter storms.

Climate change has a major impact on people and their actions, as well as agricultural resources and water availability, and is very important in areas where agriculture is the main source of economic activity, such as most parts of Nanjing. Agriculture and fisheries are both heavily impacted by climate change. Drought and flood frequency and severity can fluctuate, causing challenges for farmers and ranchers and placing food safety at risk. As a result, studying climate change is important for humans.

This paper presents the trend analysis of temperature, precipitation, relative humidity, sunshine hour (the effect of climate variation) in the city of Nanjing, China from 1951 to 2020. I hope to find variations of these factors. Not only that but also find the relationship among climate factors. It is very important to guess a factor's variation when one factor is changed. Through this information, easy to understand climate change; helps to manage day-to-day life. Not only that but also information provide up-to-date information for better climate change management in the city.

B. *Domestic and international Research progress*

The results show that around the middle of the 1970s, precipitation maxima shifted from relatively stable patterns to a major increasing/decreasing trend. In terms of annual variability, rainy days are decreasing, and precipitation intensity is increasing, with a notable increase in precipitation intensity recorded in the Yangtze River basin's middle and lower reaches (Zhang et al. 2008). A significant temperature rise tends to speed up the evaporation process and lower the amount of water available to wetlands. Temperature rises tend to increase evaporation and lower wetlands' water levels, especially in endorheic basins and arid regions (Xue et al. 2018.). Climate is a model of a complicated system that includes the atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere, as well as interactions between them. The Global temperature, which had been rising several times, peaked in 1998 and then stopped (Mudelsee, 2019.). Increased GHG levels will have a direct impact on global warming and climate change. Higher temperatures during the day and night, as well as significant rainfall patterns with significant rainfall intensity in a short period, have been seen. Hermon (2014) (Hermon, 2014.).Industrial growth, greenhouse gases such as carbon dioxide, methane, and nitrous oxide may be leading to temperature increase (Bhuyan et al. 2018).

Our findings show considerable variation between stations with decrease and increase precipitation trends at the annual, seasonal, and monthly scales, with major increasing trends primarily occurring in January, August, winter, and summer, and major declining trends primarily occurring in October and autumn. Most precipitation indicators indicate that both the intensity and the number of days with excessive precipitation are growing; the mean precipitation amount, particularly on a wet day, indicates a strong increase trend. When it comes to precipitation concentration, the monthly rainfall heterogeneity shows a minor downward tendency, whereas the contribution of the days with the most precipitation shows a large upward tendency. When it comes to precipitation concentration, monthly rainfall heterogeneity shows a negligible decrease trend, whereas the contribution of the wettest days shows a negligible increase trend (Huang et al. 2013.).

The decrease in sunshine hours is greatest during the summer and lowest during the winter; Inland and plain regions see the greatest reduction in sunshine hours, whereas northwest mountain and coastland regions experience the least; sunlight hours have a strong relationship with precipitation, relative humidity, and wind speed, with wind speed having the most impact on sunlight hours, as suggested by the close temporal and geographic relationship between the two variables; cloud cover is unlikely to be a substantial driver of decreasing sunshine hours since it is more or less steady; wind speed is a significant driving factor of decreasing sunshine hours in North China, both geographically and seasonally (Yang et al. 2009.). Because the solar elevation is lowest in the winter, the sunshine duration recorder should be most sensitive to variations in aerosol concentration. Furthermore, because winter is the season with the lowest background aerosol loading, reductions in aerosol emissions should have a higher impact (Sanchez-Lorenzo et al. 2008.).

December has the shortest sunshine duration (average areal total - 39.7 hours), while July has the longest (average areal total - 230.1 hours). In Poland, the spatial variation of sunshine duration shows a considerable deal of variation due to varying day lengths depending on latitude. The isolines of totals of sunshine duration flow from the highest values in the south to the lowest in the north of the country during the cool months (November, December, January, February), while the pattern is inverted during the warmer seasons (March to September) (Bartoszek et al. 2021.). When comparing sunshine duration records with comparable total cloud cover data, the expected negative correlation between these variables is often not apparent, especially when looking at long-term trends (Wang et al. 2012.).

In Italy, there is no indication of a strong linkage between air temperature and the temporal evolution of SD: substantial temperature trends exist even when SD trends do not, and major regional differences in SD trends do not correspond to substantial regional differences in temperature trends. The lack of a large SD effect on temperature long-term variability is likely because an increase in SD creates a decrease in daily minimum values, which is associated with a reduction in cloudiness, in addition to an increase in daily maximum temperatures (Vyssoki et al. 2014.). The findings show that: (1) both temperature and precipitation have increased over the past 45 years, but the temperature rise is more noticeable than the precipitation rise; (2) for temperature increase, the higher the latitude and elevation, the faster the increase, though the latitude has a stronger influence on the increase. In the summer, northern Xinjiang warms up faster than southern Xinjiang; (3) in northern Xinjiang and the summer in southern Xinjiang, precipitation rises mostly in the winter. Although both temperature and precipitation increased in general, the increase is different inside Xinjiang: Ili, which has the most precipitation in Xinjiang, shows a moderate increase in precipitation. Hurst index (H) study indicates that existing patterns in climate change will continue (Li et al. 2011.). For China as a whole, the number of days with a daily maximum temperature above 35°C has been declining. Eastern China was particularly affected by the downward trend. Furthermore, the number of frost days showed a considerable downward trend, implying that China's frost-free season has been greatly extended (Zhai and Pan. 2003). Winter and spring climate warming were more noticeable than other seasons, and the summer warming trend was determined to be the weakest practically everywhere. Surprisingly, the summer means the temperature in the Yangtze and Huaihe River basins decreased little (Ren et al. 2012.).

Nanjing's warming trend is extremely mild; the chief temperature change is a rising temperature in winter, while it was not noticeable in summer, reducing the heatwave phenomena, and the average year temperature has grown slightly; over the years, precipitation has grown, but sunlight hours have decreased, in addition to the city dark island impact (YingXiang et al. 2014.). Summer mean maximum temperature (TxS) shows the greatest increase in most parts of China, except for the southwest, whereas winter means minimum temperature (TnW) shows small cooling trends (Li et al. 2015.) The average yearly maximum and minimum temperatures have been raised. The mean yearly temperature change suggests a considerable fluctuation of temperature readings of about 1.5 degrees Celsius. According to the socioeconomic data study, 78 percent of the sample households experienced a rise in yearly temperature and 66.7 percent experienced a drop in yearly rainfall (Li et al. 2015.). Weather extremes in the capital city may be made worse by the rising trend in temperature caused by climate change and other causes (Alemu et al. 2020.). There was no discernible rise in rainfall extremes over the NAHPP, and several sites exhibited no discernible decrease (Du et al. 2021.).

In addition to SSR, aerosols have an impact on temperature, precipitation, and climate. Changes in temperature and precipitation have an extra impact on rice output because of climate change (Wang et al. 2020.). Apart from geometrical/astronomical variables, the principal causes causing losses of surface solar radiation (SSR) under clear sky conditions include aerosols and water vapor. In most parts of China, aerosols cause the most attenuation in clear-sky SSR in April, while water vapor causes the greatest attenuation in clear-sky SSR in July in North China and the Yangtze River Delta, and monthly solar radiation losses due to water vapor are larger than those due to aerosols (Yu et al. 2021.). Taking climate change effects into account, the regional distribution of 100-year return period rainfall predictions. It is noticeable that the southern section of the country receives heavy to moderate rainfall, but the northern section receives less (Alahmadi and Rahman, 2020.). The findings demonstrate that in the research region, wet day precipitation, consecutive wet days, and the frequency of heavy precipitation days all show non-significant declining trends (Zhao et al. 2014.).

The world climate and environment have altered dramatically in the last 100 years, with global warming being the most prominent feature. These modifications have had a substantial impact on China's climate and ecosystem (QIN et al. 2005.). During the period 2011-2017, the heating degree days in winter grew first, then reduced, whereas the cooling degree days in summer reduced first, then increased (Li et al. 2018.). Using appropriate statistical techniques, the Mann Kendal trend test was used to examine long-term data for several elements of the climate in Andhra Pradesh's East Coast. The results show that extreme temperature variability is growing throughout the season. For the winter season, the change is substantially higher than for the other seasons (Siraj et al. 2013.). Precipitation and Actual annual temperature data for nine selected weather stations, regionally scattered across Canada, are used to test the hypothesis of increasing temperature and precipitation trends related to global climate change (Clark et al. 2000.).

C. Research content.

The climate change trend in Nanjing, China from 1951 to 2020 were analyzed. Temperature, precipitation, sunshine hour, and relative humidity are the factors, which choose to study. The content of this study is mainly based on climate change trend analysis. The analysis is done in two ways. The annual climate change trend in Nanjing from 1951 to 2020 is one of the main parts of the studies. Annual average temperature trend, annual maximum temperature trend, annual minimum temperature trend, annual relative humidity trend, and annual sunshine hour trend are the main focus areas. Another path of study is the seasonal climate change trend in Nanjing from 1951 to 2020. Autumn, spring, summer, and winter are the four seasons in Nanjing.

II. MATERIALS AND METHODS

A. Study Area

Nanjing is the capital of Jiangsu Province in the People's Republic of China and the region's second-largest city. Nanjing, which is situated in southwestern Jiangsu and has 11 districts, has an administrative area of 6,600 km2 and a population of 8,505,500 people as of 2019 Nanjing is located in the middle of the lower reaches of the Yangtze River, the east of China, a national and regional center city in china at 118°22′~ 119° 14′E， 31°14′~ 32° 37′N, belongs to the northern subtropics monsoon climate zone, four seasons, mild climate, moderate rainfall.

When considering climate factors, the main highlights factors are temperature and precipitation. The annual mean temperature is 21□, the highest temperature is 26 □ and the lowest temperature is 16 □ in Nanjing. The average daily precipitation is 43.6 mm and the annual precipitation is 543.8 mm, only 86% of the average level in China (630 mm). When considering the number of other factors of climate in Nanjing, the average wind speed is 9 km/h, humidity is 71%, the dew point is 15 □, and visibility is 8 km. normally the hottest month and coldest month in Nanjing are July and January. Its average temperature is 29
-□ and 3□. In order, July and March are the wettest month and the windiest month.

B. Data sources

Various climate factors were choose in the study. They are temperature, sunshine hour, precipitation, and relative humidity. These factors were used to analyze the changing trend from 1951 to 2020 in Nanjing, China. The initial data set of daily that climate factors amount for the period 1951 to 2020 were collected from the National meteorological information centre of China.

C. Methods

As the first step in the data analysis, daily records of meteorological factors, including temperature, relative humidity, precipitation, and sunshine hour were screened from the primary data for the period spanning 01 January 1951 to 31 December 2020. Then downloaded data were divided into monthly data and they were a category into four periods of autumn, spring, summer, winter. Autumn is from October to November, spring is from March to May, summer is from June to September and winter is from December to February in Nanjing. Different statistical tests were used to determine change point analysis and trend detection for identifying climate change effects on a monthly, annual, and seasonal basis for maximum temperature, minimum temperature,total rainfall, and sunshine hour basis. Mann- Kendall trend test was used for analysis.

The Mann-Kendall trend test is used to detect whether or not a particular time series data has a linear monotonic trend. It's a non-parametric trend that's strongly related to Kendall's correlation coefficient. The null hypothesis, H0, indicates that no monotonic trend exists, and it is tested against one of three alternative hypotheses: Ha: (i) an upward monotonic trend exists, (ii) a downward monotonic trend exists, or (iii) either an upward monotonic trend or a downward monotonic trend exists. It's a reliable trend detection test that's commonly used in financial, climatological, hydrological, and environmental time series analysis.

As the computed p-value, which is computed using an exact method, is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha. The risk of rejecting the null hypothesis H0 while it is true is less than 0.1%. R-square can have any value between 0 and 1, with a value closer to 1 suggesting that the model accounts for a greater amount of variation.

III. RESULT AND DISCUSSION

Precipitation, temperature, sunshine hour, and relative humidity were analyzed. Annual and seasonal data were analyzed to get a clear idea about the changing trend.

A. Annual Temperature Changes

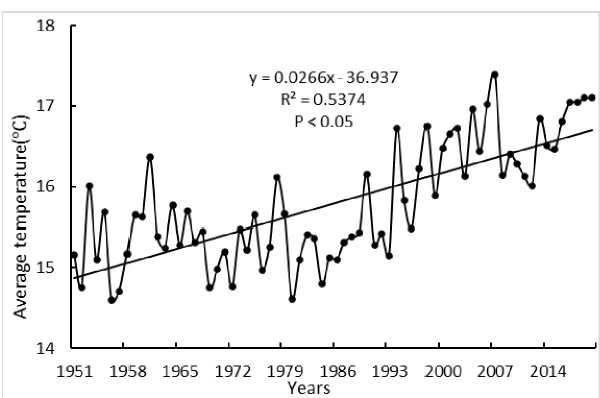

Fig. 1 Changes trends of annual average temperature

Figure 1, the trend line indicates that a significant annual average temperature increase was observed from 1951 to 2020. The mean annual temperature is 15.79℃. The lowest average temperature was recorded from 1956 and the highest average temperature was recorded from 2007. They are 14.59℃ (1.2℃ lower than the mean) and 17.39℃ (1.6℃ higher than the mean) respectively. The R-square value of the annual average temperature data is 0.537. An increasing trend of average annual temperature in Nanjing was displayed. The annual average temperature was changed by a factor of 0.027. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 1 was an increasing trend and statically significant.

B. Changes trends of annual average maximum temperature

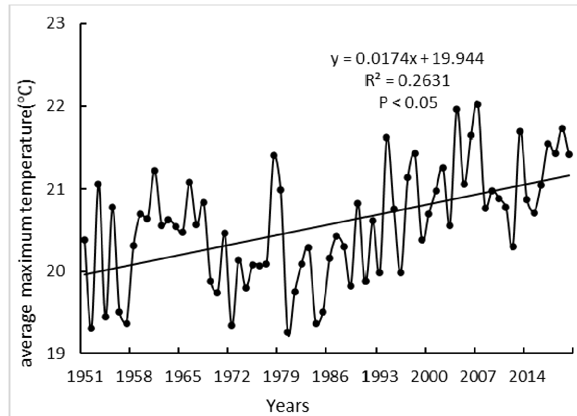

Fig. 2 Changes trends of annual average maximum temperature

Figure 2 the lowest average maximum temperature was recorded from 1980 and the highest average maximum temperature was recorded from 2007. They are 19.3□ (1.3□ lower than the mean) and 22□ (1.5□ higher than the mean) respectively. The annual average maximum temperature was changed by a factor of 0.017. The mean annual maximum temperature is 20.6□. The R-square value of the annual average maximum temperature data is 0.263. There was a significant increasing trend of annual average maximum temperature. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 2 was an increasing trend and statically significant.

C. Changes trends of annual average minimum temperature

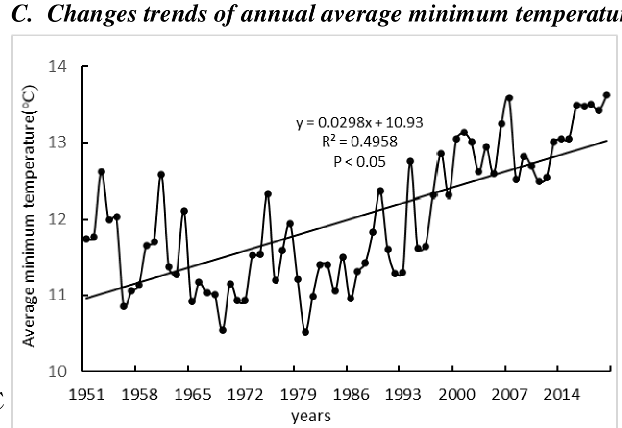

Fig. 3 Changes trends of annual average minimum temperature

As indicated in figure 3 the trend line indicates that a significant annual average minimum temperature change was observed from 1951 to 2020. The annual average minimum temperature was changed by a factor of 0.030. The mean annual minimum temperature is 12℃. The lowest average minimum temperature was recorded from 1980 and the highest average minimum temperature was recorded from 2020. They are 10.5℃ (1.5℃ lower than the mean) and 13.6℃ (1.6℃ higher than the mean) respectively. There was a simultaneous increase in minimum temperature from 1993 to 1994. The R-square value of the annual average minimum temperature data is 0.537 and remarkable increasing trend of average annual minimum temperature in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 3 was an increasing trend and statically significant.

D. Seasonal Temperature Changes

Seasonal Average Temperature Changes

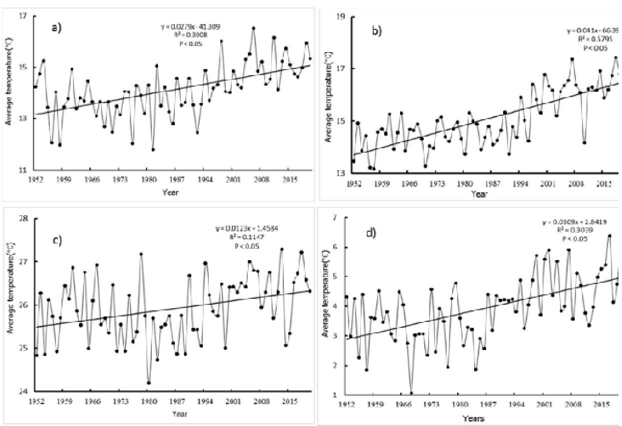

Fig. 4 Changes trends of average temperature in autumn (a) spring (b) summer (c) winter (d)

The trend line in figure 4 (a) shows that there was a significant average temperature change in autumn from 1951 to 2020. The mean temperature in autumn is 14.1℃. The lowest average temperature was recorded from 1981 and the highest average temperature was recorded from 2006. They are 11.8℃ (2.3℃ lower than the mean) and 16.5℃ (2.4℃ higher than the mean) respectively. The R-square value of the average temperature in autumn data is 0.300. The temperature in autumn was changed by a factor of 0.028. There was an increasing trend in average temperature in autumn. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 4 (a) was an increasing trend and statically significant.

Figure 4 (b), the trend line indicates that a significant average temperature change in spring was observed from 1951 to 2020. The mean temperature in spring is 15.1□. The lowest average temperature was recorded from 1957 and the highest average temperature was recorded from 2018. They are 13.2□ (1.9□ lower than the mean) and 17.4□ (2.3□ higher than the mean) respectively. The R-square value of the average temperature in spring data is 0.579. The temperature in the spring was changed by a factor of 0.041. Increase trend of average temperature in spring was displayed in Nanjing. P-value is less than the level of significance.

The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 4 (b) was an increasing trend and statically significant.

Figure 4 (c), the trend line indicates that a significant average temperature change in summer was observed from 1951 to 2020. The mean temperature in summer is 25.9□. The lowest average temperature was recorded from 1980 and the highest average temperature was recorded from 2013. They are 24.2□ (1.7□ lower than the mean) and 27.3□ (1.4□ higher than the mean) respectively. The R-square value of the average temperature in summer data is 0.114. The temperature in summer was changed by a factor of 0.012. There was a simultaneous increase in average temperature in summer from 1977 to 1978 and there was a simultaneous decrease from 1978 to 1980. An increasing trend of average temperature in summer was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 4 (c) was an increasing trend and statically significant.

Figure 4 (d), the trend line indicates that a significant average temperature change in winter was observed from 1951 to 2020. The mean temperature in winter is 3.9□. The lowest average temperature was recorded from 1968 and the highest average temperature was recorded from 2020. They are 1.1□ (2.9□ lower than the mean) and 6.9□ (2.9□ higher than the mean) respectively. The R-square value of the average temperature in winter data is 0.304. The temperature in winter was changed by a factor of 0.031. An increasing trend of average temperature in winter was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 4 (d) was an increasing trend and statically significant.

During the study period, the seasonal temperature was not uniform variation. The mean average temperature change in summer was the highest and the winter was the lowest. Spring was higher than autumn.

Seasonal Maximum Temperature Changes

Figure 5 (a), the trend line indicates that a significant average maximum temperature change in autumn was observed from 1951 to 2020. The mean maximum temperature in autumn is 19.3□. The lowest average maximum temperature was recorded from 1981 and the highest average maximum temperature was recorded from 1998. They are 15.9□ (3.4□ lower than the mean) and 21.7□ (2.4□ higher than the mean) respectively. The R-square value of the average maximum temperature in autumn data is 0.098. The average maximum temperature in autumn was changed by a factor of 0.016. There was a simultaneous decrease in average maximum temperature in autumn from 1980 to 1981.

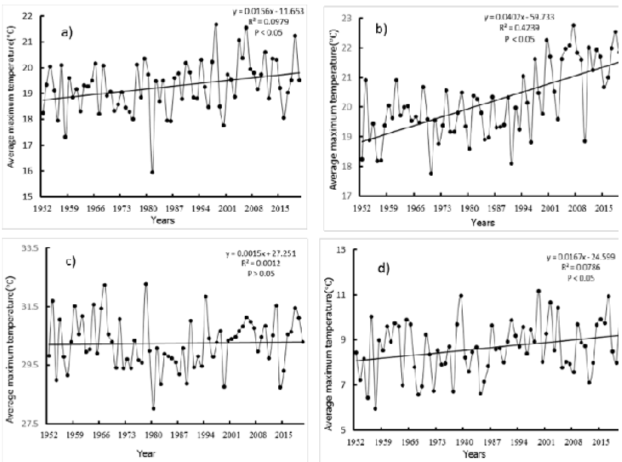

Fig. 5 Changes trends of average maximum temperature in autumn (a) spring (b) summer (c) winter (d)

An increasing trend of average maximum temperature in autumn was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 5 (a) was an increasing trend and statically significant.

Figure 5 (b), the trend line indicates that a significant average maximum temperature change in spring was observed from 1951 to 2020. The mean maximum temperature in spring is 20.2℃. The lowest average maximum temperature was recorded from 1970 and the highest average maximum temperature was recorded from 2007. They are 17.8℃ (2.4℃ lower than the mean) and 22.7℃ (2.6℃ higher than the mean) respectively. The R-square value of the average maximum temperature in spring data is 0.424. The average maximum temperature in spring was changed by a factor of 0.040. There was a simultaneous decrease in average maximum temperature in spring from 2009 to 2010. There was an increasing trend of average maximum temperature in spring. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 5 (b) was an increasing trend and statically significant.

Figure 5 (c), the trend line indicates that a significant average maximum temperature change in summer was observed from 1951 to 2020. The mean maximum temperature in summer is 30.3℃. The lowest average maximum temperature was recorded from 1980 and the highest average maximum temperature was recorded from 1978. They are 28℃ (2.2℃ lower than the mean) and 32.3℃ (2℃ higher than the mean) respectively. The R-square value of the average maximum temperature in summer data is 0.001. The average maximum temperature in summer was changed by a factor of 0.002. There was a simultaneous increase in average maximum temperature in summer from 1977 to 1978 and there was a simultaneous decrease from 1978 to 1980.

Figure 5 (d), the trend line indicates that a significant average maximum temperature change in winter was observed from 1951 to 2020. The mean maximum temperature in winter is 8.6℃. The lowest average maximum temperature was recorded from 1957 and the highest average maximum temperature was recorded from 1999. They are 6℃ (2.7℃ lower than the mean) and 11.2℃ (2.5℃ higher than the mean) respectively. The R-square value of the average maximum temperature in winter data is 0.078. The average maximum temperature in winter was changed by a factor of 0.017. An increasing trend of average maximum temperature in winter was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 5 (d) was an increasing trend and statically significant.

During the study period, the seasonal average maximum temperature was not uniform variation. The highest mean average maximum temperature was in summer and the lowest was in winter.

Seasonal Minimum Temperature Changes

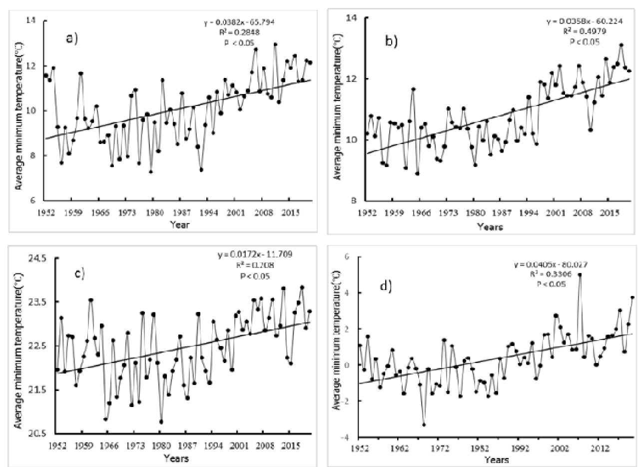

Fig. 6 Changes trends of average minimum temperature in autumn (a) spring (b) summer (c) winter (d)

Figure 6 (a), the trend line indicates that a significant average minimum temperature change in autumn was observed from 1951 to 2020. The mean minimum temperature in autumn is 10.1℃. The lowest average minimum temperature was recorded from 1979 and the highest average minimum temperature was recorded from 2011. They are 7.3℃ and 13℃ respectively. The R-square value of the average minimum temperature in autumn data is 0.285. The average minimum temperature in autumn was changed by a factor of 0.038. increase trend of average minimum temperature in autumn was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 6 (a) was an increasing trend and statically significant.

Figure 6 (b), the trend line indicates that a significant average minimum temperature change in spring was observed from 1951 to 2020. The mean minimum temperature in spring is 10.8℃. The lowest average minimum temperature was recorded from 1965 and the highest average minimum temperature was recorded from 2018. They are 8.9℃ and 13.1℃ respectively. The R-square value of the average minimum temperature in spring data is 0.498. The average minimum temperature in spring was changed by a factor of 0.036. There was an increasing trend of average minimum temperature in spring. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 6 (b) was an increasing trend and statically significant.

Figure 6 (c), the trend line indicates that a significant average minimum temperature change in summer was observed from 1951 to 2020. The mean minimum temperature in summer is 22.5℃. The lowest average minimum temperature was recorded from 1980 and the highest average minimum temperature was recorded from 2018. They are 20.8℃ and 23.8℃ respectively. The R-square value of the average minimum temperature in summer data is 0.208. The average minimum temperature in summer was changed by a factor of 0.017. There was a simultaneous decrease in average minimum temperature in summer from 1964 to 1965 and from 1978 to 1980. Increase trend of average minimum temperature in summer was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 6 (c) was an increasing trend and statically significant.

Figure 6 (d), the trend line indicates that a significant average minimum temperature change in winter was observed from 1951 to 2020. The mean minimum temperature in winter is 0.4℃. The lowest average minimum temperature was recorded from 1968 and the highest average minimum temperature was recorded from 2007. They are -3.3℃ and 5℃ respectively. The R-square value of the average minimum temperature in winter data is 0.331. The average minimum temperature in winter was changed by a factor of 0.040. There was an increasing trend of average minimum temperature in winter. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 6 (d) was an increasing trend and statically significant.

During the study period, the seasonal average maximum temperature was not uniform variation. The highest mean minimum temperature was in summer and the lowest was in winter. Summer mean maximum temperature shows the greatest increase in most parts of China, except for the southwest, whereas winter means minimum temperature shows small cooling trends (Li et al. 2015.) Increased GHG levels will have a direct impact on global warming and climate change. Higher temperatures during the day and night, as well as significant rainfall patterns with significant rainfall intensity in a short period, have been seen. (Hermon .2014).

E. Annual Relative humidity Changes

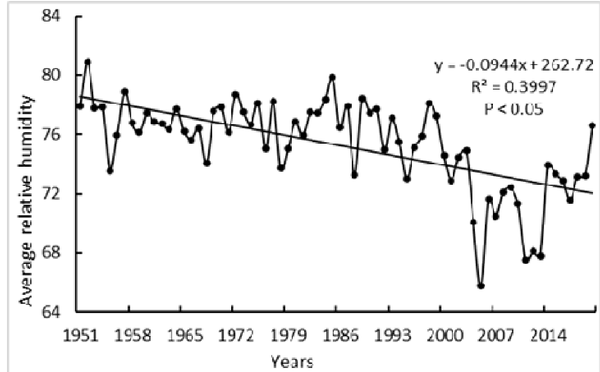

Fig. 7 Changes trends of annual average relative humidity

As indicated in figure 7, the trend line indicates that annual average relative humidity change was observed from 1951 to 2020. Annual average relative humidity was changed by a factor of -0.094 and the trend was decreasing. The mean annual relative humidity is 75.30. The lowest average relative humidity was recorded from 2005 and the highest average relative humidity was recorded from 1952. They are 65.76 (9.54lower than the mean) and 80.92 (5.62 higher than the mean) respectively. There was a simultaneous decrease in relative humidity from 2003 to 2005. The R-square value of the annual average relative humidity data is 0.399 P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected and statically significant.

F. Seasonal Relative Humidity Changes

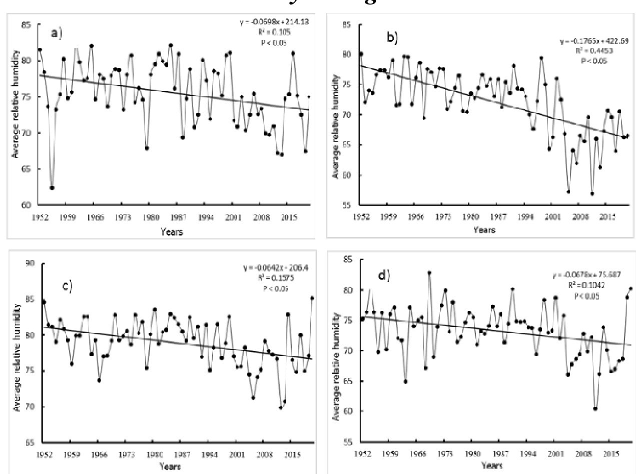

Fig. 8 Changes trends of average relative humidity in autumn (a) spring (b) summer (c) winter (d)

Figure 8 (a), the trend line indicates that average relative humidity change in autumn was observed from 1951 to 2020. The mean relative humidity in autumn is 75.56. The lowest average relative humidity was recorded from 1955 and the highest average relative humidity was recorded from 1985. They are 62.41 (13.15 lower than the mean) and 82.15 (6.59 higher than the mean) respectively. The R-square value of the average relative humidity in autumn data is 0.105. Average relative humidity in autumn was changed by a factor of -0.07. There was a simultaneous decrease in average relative humidity in autumn from 1954 to 1955 and there was a simultaneous increase in average relative humidity in autumn from 1955 to 1956 and from 1979 to 1980. decrease trend of relative humidity in autumn was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 8 (a) was statically significant.

Figure 8 (b), the trend line indicates that average relative humidity change in spring was observed from 1951 to 2020. The mean relative humidity in spring is 72.14. The lowest average relative humidity was recorded from 2011 and the highest average relative humidity was recorded from 1952. They are 56.92 (15.22 lower than the mean) and 80.08 (7.93 higher than the mean) respectively. The R-square value of the average relative humidity in spring data is 0.445. Average relative humidity in spring was changed by a factor of -0.177. A decreasing trend of average relative humidity was displayed in spring. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 8 (b) was statically significant.

Figure 8 (c), the trend line indicates that average relative humidity change in summer was observed from 1951 to 2020. The mean relative humidity in summer is 78.91. The lowest average relative humidity was recorded from 2012 and the highest average relative humidity was recorded from 2020. They are 69.90 (9.01 lower than the mean) and 85.17 (6.26 higher than the mean) respectively. The R-square value of the average relative humidity in summer data is 0.158. Average relative humidity in summer was changed by a factor of -0.064. There was a simultaneous increase in average relative humidity in summer from 2013 to 2014. A decreasing trend of average relative humidity in summer was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 8 (c) statically significant.

Figure 8 (d), the trend line indicates that average relative humidity change in winter was observed from 1951 to 2020. The mean relative humidity in winter is 73.31. The lowest average relative humidity was recorded from 2011 and the highest average relative humidity was recorded from 1969. They are 60.54 (12.77 lower than the mean) and 82.85 (9.54 higher than the mean) respectively. The R-square value of the average relative humidity in winter data is 0.104. Average relative humidity in winter was changed by a factor of -0.068. An decrease trend of average relative humidity in winter was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 8 (d) was statically significant.

During the study period, the seasonal average relative humidity was not uniform variation. The mean average relative humidity change in summer was the highest and the spring was the lowest. Autumn was higher than the winter.

G. Annual Precipitation Changes

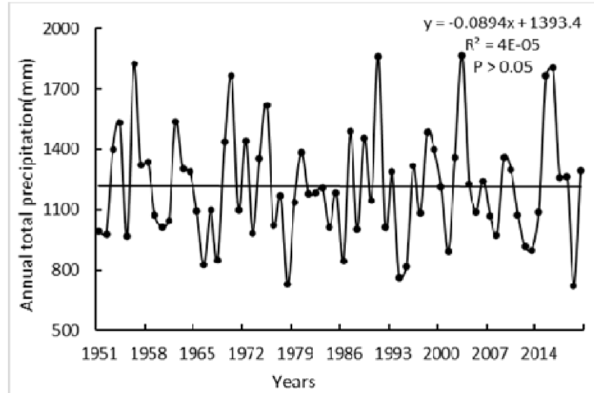

Fig 9 Changes trends of annual total precipitation

As indicated in figure 9, the trend line indicates that total precipitation change was observed from 1951 to 2020. Annual total precipitation was changed by a factor of -0.089. The mean annual total precipitation is 1215.8mm. The highest annual total precipitation was recorded in 1956, 1970, 1991, 2003, 2015, and 2016.

The lowest annual total precipitation was in 1978, 1994, 1995, 2001, and 2019. Among these years, the lowest total precipitation was recorded from 2019 and the highest total precipitation was recorded from 2003. They are 721.8mm (503 lower than the mean) and 1867.4mm (651.6mm higher than the mean) respectively. There was a simultaneous increase in precipitation from 1995 to 1996, from 1968 to 1970, from 1990 to 1991, from 2001 to 2003, and 2013 to 2016. There was a simultaneous decrease from 1991 to 1992. The R-square value of the annual total precipitation data is 0.00004. P-value is higher than the level of significance. Null hypothesis Ho cannot reject and the risk to reject the null hypothesis H0 while it is true is 97.57%. This is not statistically significant.

H. Seasonal Precipitation Changes

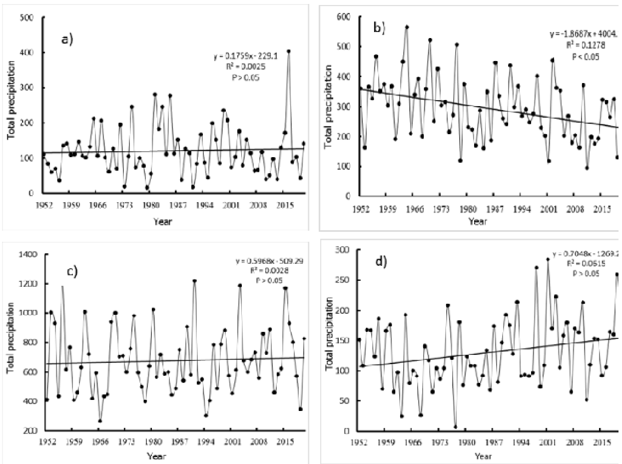

Fig. 10 Changes trends of total precipitation in autumn (a) spring (b) summer (c) winter (d)

Figure 10 (a), the trend line indicates that total precipitation change in autumn was observed from 1951 to 2020. The mean total precipitation in autumn is 120.2mm. The lowest total precipitation was recorded from 1979 and the highest total precipitation was recorded from 2016 in autumn. They are 15.1mm (105.1mm lower than the mean) and 403.4mm (283.2mm higher than the mean) respectively. The R-square value of the total precipitation in autumn data is 0.0025. Total precipitation in autumn was changed by a factor of 0.176. There was a simultaneous increase in total precipitation in autumn from 2015 to 2016. There was a simultaneous decrease in total precipitation in autumn from 2016 to 2017.

Figure 10 (b), the trend line indicates that total precipitation change in spring was observed from 1951 to 2020. The mean total precipitation in spring is 292.8mm. The lowest total precipitation was recorded from 2011 and the highest total precipitation was recorded from 1964. They are 95.4mm (197.4mm lower than the mean) and 566.1mm (273.3mm higher than the mean) respectively. The R-square value of the total precipitation in spring data is 0.128. Total precipitation in spring was changed by a factor of -1.87. A decreasing trend of total precipitation in spring was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 10 (b) was statically significant.

Figure 10 (c), the trend line indicates that total precipitation change in summer was observed from 1951 to 2020. The mean total precipitation in summer is 676mm. The lowest total precipitation was recorded from 1966 and the highest total precipitation was recorded from 1991. They are 265.8mm (410.2mm lower than the mean) and 1219.6mm (543.6mm higher than the mean) respectively. The R-square value of the total precipitation in summer data is 0.003. Total precipitation in summer was changed by a factor of 0.597. There was a simultaneous increase in total precipitation in summer from 1955 to 1956, from 1990 to 1991, from 2002 to 2003, and 2014 to 2015. There was a simultaneous decrease in total precipitation in summer from 1991 to 1992.

Figure 10 (d), the trend line indicates that total precipitation change in winter was observed from 1951 to 2020. The mean total precipitation in winter is 130.5mm. The lowest total precipitation was recorded from 1977 and the highest total precipitation was recorded from 2001. They are 6.9mm (123.6mm lower than the mean) and 284.5mm (154mm higher than the mean) respectively. The R-square value of the total precipitation in winter data is 0.062. Total precipitation in winter was changed by a factor of 0.705. There was a simultaneous increase in total precipitation in winter from 1963 to 1964, from 1997 to 1998, and from 2000 to 2001. There was a simultaneous decrease from 1998 to 1970.

During the study period, the seasonal total precipitation was not uniform variation. The mean total precipitation change in summer was the highest and the autumn was the lowest. Spring was higher than the winter. The result shows that the Nanjing city of annual precipitation trend was upward and annual precipitation will decrease in the future. The summer was a significant upward trend, and it will increase in future. Autumn was a downward trend, and it will decrease in future. Winter was upward trend, and it will increase in future (Yin. 2015).

I. Annual Sunshine Hour Changes

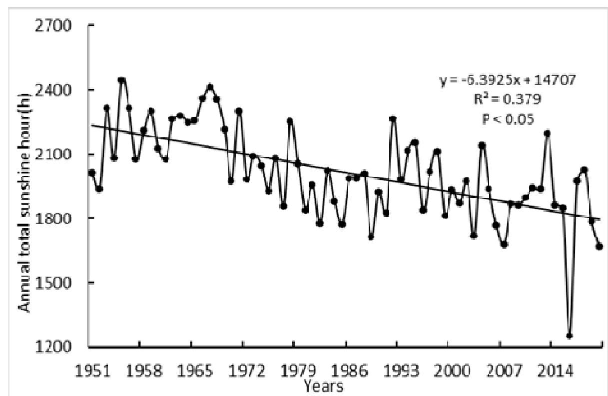

Fig. 11 Changes trends of the annual total sunshine hour.

As indicated in figure 11, the trend line indicates that annual total sunshine hour change was observed from 1951 to 2020. The annual total sunshine hour was changed by a factor of -6.393. The mean annual total sunshine hour is 2015.10h. The lowest total sunshine hour was recorded from 2016 and the highest total sunshine hour was recorded from 1955. They are 1251.90h (763.20h lower than the mean) and 2446.70h (431.60h higher than the mean) respectively.

There was a simultaneous decrease in an annual total sunshine hour from 2015 to 2016 and there was a simultaneous increase from 2016 to 2017. The R-square value of the annual total sunshine hour data is 0.379. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 11 was statically significant.

J. Seasonal Sunshine Hour Changes

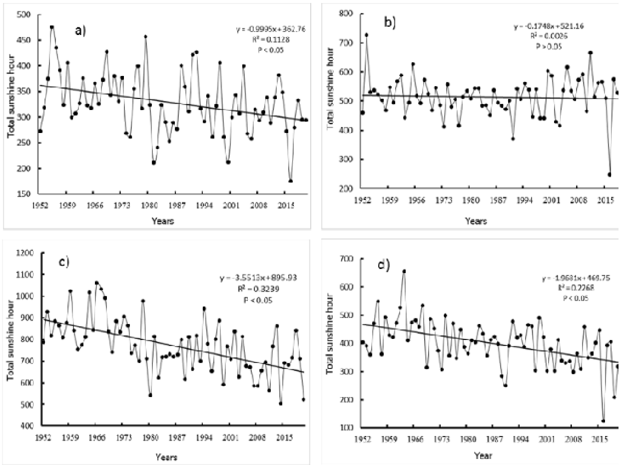

Fig. 12 Changes trends of total sunshine hour in autumn (a) spring (b) summer (c) winter (d)

Figure 12 (a), the trend line indicates that total sunshine hour change in autumn was observed from 1951 to 2020. The mean total sunshine hour in autumn is 327.77h. The lowest total sunshine hour was recorded from 2016 and the highest total sunshine hour was recorded from 1955. They are 175.00h (157.77h lower than the mean) and 476.00h (148.23h higher than the mean) respectively. The R-square value of the total sunshine hour in autumn data is 0.113. The total sunshine hour in autumn was changed by a factor of -0.99. The decreasing trend of the total sunshine hour was displayed in autumn, but it is not a clear trend. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 12 (a) was statically significant.

Figure 12 (b), the trend line indicates that total sunshine hour change in spring was observed from 1951 to 2020. The mean total sunshine hour in spring is 515.04h. The lowest total sunshine hour was recorded from 2016 and the highest total sunshine hour was recorded from 1953. They are 248.20h (266.84h lower than the mean) and 728.00h (212.96h higher than the mean) respectively. The R-square value of the total sunshine hour in spring data is 0.003. The total sunshine hour in spring was changed by a factor of -0.175. There was a simultaneous increase in the total sunshine hour in spring from 2016 to 2017. There was a simultaneous decrease in the total sunshine hour in spring from 2015 to 2016.

Figure 12 (c), the trend line indicates that total sunshine hour change in summer was observed from 1951 to 2020. The mean total sunshine hour in summer is 771.63h. The lowest total sunshine hour was recorded from 2014 and the highest total sunshine hour was recorded from 1966. They are 504.70h (266.93h lower than the mean) and 1060.50h (288.87h higher than the mean) respectively. The R-square value of the total sunshine hour in summer data is 0.323. The total sunshine hour in summer was changed by a factor of -3.551. The decreasing trend of total sunshine in summer was displayed in Nanjing. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 12 (c) was statically significant.

Figure 12 (d), the trend line indicates that total sunshine hour change in winter was observed from 1951 to 2020. The mean total sunshine hour in winter is 400.87h. The lowest total sunshine hour was recorded from 2016 and the highest total sunshine hour was recorded from 1963. They are 125.30h (275.57h lower than the mean) and 655.20h (254.33h higher than the mean) respectively. The R-square value of the total sunshine hour in winter data is 0.227. The total sunshine hour in winter was changed by a factor of -1.968. There was a simultaneous increase in the total sunshine hour in winter from 2016 to 2015. There was a simultaneous decrease in the total sunshine hour in winter from 2015 to 2016. The decreasing trend of the total sunshine hour was displayed in winter. P-value is less than the level of significance. The alternative hypothesis was accepted, and the null hypothesis Ho was rejected. Figure 12 (d) was statically significant.

During the study period, the seasonal total sunshine hour was not uniform variation. The mean total sunshine hour change in summer was the highest and the autumn was the lowest. Spring was higher than the winter. Sunshine hours in southwestern China are influenced by changes in water vapor and cloud cover. Furthermore, higher surface downwards solar radiation flux contributed to an increase in sunshine hours from 1991 to 2009. The influence of urbanization on sunshine hours may be reflected in the bigger decrease trends of sunlight hours at urban stations than at rural stations. (LI et al. 2012)

Sunshine hours have a strong relationship with precipitation, relative humidity, and wind speed, with wind speed having the most impact on sunlight hours, as suggested by the close temporal and geographic relationship between the two variables; cloud cover is unlikely to be a substantial driver of decreasing sunshine hours since it is more or less steady; wind speed is a significant driving factor of decreasing sunshine hours in North China, both geographically and seasonally (Yang et al. 2009.)

The correlation coefficient of temperature and relative humidity is -0.624. There is a negative relationship it means when one factor is increases, the other factor is decreases. Not only these two factors but also Correlation coefficient of temperature and precipitation is -0.14345 and temperature and sunshine hour is -0.3149. Precipitation and relative humidity have a correlation value of 0.264. There is a positive relationship it means when one factor is increases; the other factor is increased too. Not only these two factors but also a sunshine hour and relative humidity had a positive relationship. The correlation coefficient was 0.10106.

The global climate and environment have changed greatly in the last 100 years, with global warming being the most key feature. These changes have exerted a major effect on China's climate and environment. (Qin et al. 2005.)

IV. CONCLUSIONS

From 1951 to 2020, this research was present the trend in temperature, precipitation, relative humidity, and sunshine hour (the effect of climate variation) in Nanjing, China. It is very important to take a clear idea about climate change. The mean annual average temperature is 15.8℃. The lowest average temperature was recorded from 1956 and the highest average temperature was recorded from 2007. The mean annual average temperature was increasing trend and statically significant. The mean annual maximum temperature and minimum temperature were 20.6℃ and 12℃ respectively and the trend was increased. The mean average temperature change in summer was the highest and the winter was the lowest.

The mean annual total precipitation was 1215.8mm. The lowest total precipitation was recorded from 2019 and the highest total precipitation was recorded from 2003. P-value is higher than the level of significance. Null hypothesis Ho cannot reject and the risk to reject the null hypothesis H0 while it is true is 97.57%. This is not statistically significant of annual total precipitation. The mean total precipitation change in summer was the highest and the autumn was the lowest. Spring was higher than the winter. The annual total sunshine hour was changed by a factor of -6.39. The mean annual total sunshine hour is 2015.1h. The annual total sunshine hour trend was statically significant. During the study period, the seasonal total sunshine hour was not uniform variation. The mean total sunshine hour change in summer was the highest and the autumn was the lowest. Spring was higher than the winter.

ACKNOWLEDGMENT

This research was supported by many people. Without their support, I would not have been able to carry out this research successfully.

Firstly, I would love to express my heartfelt gratitude and thanks to my supervisor Prof. Xiaoya Yang, who was guiding me throughout this work. She encouraged me and pointing out the wrong and guide me in the right direction. She was well aware of the many personal difficulties that arose and helped to normalize them.

I am deeply grateful to my family, whoever it is my mother, younger brother, and grandmother. They trust me and understand me a lot. Graduation my father's dream. He makes up dreams on my mind about education I want to be grateful to him even though he passed away.

Finally, I would like to thank Mr. K.L.V.D.D Perera, M.A.I.I.J.Subhasinghe, R.V.D.Divyanjani and my dear friends encouraging me and helping me. We always share information not only about education but also about the day-to-day life. It was a great comfort to me.

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