Research paper

# Study of Long-Term Trends of Changes in Rainfall and Temperature at the Fushan Experimental Forest

Shiang-Yue Lu[1) ] Ming-Yuan Sun[2,3)] Ho-Chiao Fu[1)] Hui-Hsueh Huang[1)]

【Summary】

The Fushan Experimental Forest [FEF] is the primary site for studying environmental ecology in Taiwan. Whether the forest is affected by global warming and is undergoing changes in rainfall and temperature are concerns of many scholars and researchers. This report focused on this topic and used the Mann-Kendall trend and anomaly test methods to analyze rainfall and temperature records of the Fushan nursery weather station from January 1989 to December 2020 to explore whether there have been statistical changes in rainfall and temperature in the study area. Results indicated that the annual rainfall amount, number of rainfall-days, and number of heavy rainfall-days have increased in the FEF over the past 32 years. The increasing rates for the yearly rainfall amount, rainfall-days, and heavy rainfall-days were approximately 47.71 mm decade$^{-1}$, 9.60 d decade$^{-1}$, and 1.37 d decade$^{-1}$, respectively, with corresponding values of the Mann-Kendall test statistic ($Z_{MK}$) of 0.088, 2.644, and 0.840. Values of $Z_{MK}$ indicated that the change in the number of rainfall-days was statistically significant. Temperatures of the FEF were possibly affected by factors such as increases in the rainfall amount and the number of rainfall-days and presented a decreasing tendency. The situation was opposite to that of Taiwan's other low-elevation areas which are showing an increasing trend in temperature. Decreasing rates of the annual average temperature, and January and July average temperatures were 0.40, 0.36, and 0.58℃ decade$^{-1}$, respectively, with corresponding $Z_{MK}$ values of 2.9.3, -1.314, and -2.822. These results also indicated that declines in the annual average temperature and July average temperature reached statistical significance. Whether changes in rainfall and temperature have affected the operation of the ecosystem in the FEF is an issue that must be faced.

**Key words:** rainfall change trend, temperature change trend, Fushan Experimental Forest, Mann-Kendall trend test.

**Lu SY, Sun MY, Fu HO, Huang HH. 2021.** Study of long-term trends of changes in rainfall and temperature at the Fushan Experimental Forest. Taiwan J For Sci 36(3):235-44.

[1)] Division of Watershed Management, Taiwan Forestry Research Institute. 53 Nanhai Rd., Taipei 10066, Taiwan. 林業試驗所集水區經營組，10066台北市南海路53號。

[2)] Liukuei Research Center, Taiwan Forestry Research Institute, 198 Chun-Shing Village, Liukuei, Kaohsiung 84443, Taiwan. 林業試驗所六龜研究中心，84443高雄市六龜區中興村198號。

[3)] Corresponding author, e-mail:smy@tfri.gov.tw 通訊作者。

Received July 2021, Accepted November 2021. 2021年7月送審 2021年11月通過。

研究報告

# 福山試驗林降雨及氣溫長期變遷趨勢之研究

陸象豫[1) ] 孫銘源[2,3)] 傅鶴翹[1)] 黃惠雪[1)]

## 摘　要

林業試驗所福山試驗林是台灣地區研究環境生態的主要試驗場所，該試驗林是否受全球暖化現象的影響，而發生降雨及氣溫顯著的變化，是許多學者專家所關注的問題。本報告針對此一議題，以Mann-Kendall趨勢檢定法及距平值檢測法，分析1989年一月至2020年十二月福山苗圃氣象站的降雨及氣溫紀錄，以探討該試驗林的氣溫及降雨是否有統計上的變動趨勢。結果顯示福山試驗林在過去32年間，年降雨量、降雨天數及強降雨天數均有增加的趨勢，其增加的速率約分別為：47.71 mm decade$^{-1}$、9.60 d decade$^{-1}$及1.37 d decade-$^{1}$；而Mann-Kendall檢定的統計值($Z_{MK}$)則分別為0.088、2.644及0.840，顯示降雨天數的變遷已具有統計上的顯著性。溫度變化可能係受降雨量及降雨天數增加等因素的影響出現與台灣平地區域相反的情況，呈現遞減趨勢。年均溫、一月及七月均溫的遞減速率分別為：0.40、0.36及0.58℃ decade$^{-1}$；其$Z_{MK}$分別為：-2.9.3、-1.314及-2.822，顯示年均溫與七月均溫的遞減情況已達統計上的顯著性。降雨及氣溫的變化，是否已對福山試驗林生態系的運作造成影響，是必須面對的議題。

**關鍵詞：**降雨變遷趨勢、氣溫變遷趨勢、福山試驗林、Mann-Kendall趨勢檢定法。

**陸象豫、孫銘源、傅鶴翹、黃惠雪。**2021。福山試驗林降雨及氣溫長期變遷趨勢之研究。台灣林業科學36(3):235-44。

## INTRODUCTION

Temperature and rainfall are the main factors that dominate the climate of a region and are also the primary environmental factors that determine the type of ecosystems. They play decisive roles in biological activities and growth, water chemistry characteristics, development of the soil structure, decomposition rates of organic matter, and biological phenology. Therefore, changes in temperature and rainfall have significant, long-term impacts on the ecosystems of a region. Affected by global warming, climates in many regions of the world have undergone changes, and the frequency of abnormal climatic events has significantly increased. Issues concerning climate change, regardless of whether they are global or regional, have recently garnered increasing attention. Many studies have indicated that the regional heterogeneity in the amounts of rainfall and temperature magnitudes have significantly changed, and extreme events of both temperature and rainfall are occurring more frequently in recent years in low-elevation areas of Taiwan (Wang 2004, Chen 2008, Wu et al. 2010, Lu 2016). These phenomena are most likely influenced by global warming. In addition, consecutive days of no rainfall have also increased throughout the entire island, and this phenomenon combined with the frequent occurrence of extreme weather events has made water supply and watershed management more severe in Taiwan (Hsu and Chen 2002, Wang 2004, Wang et al. 2008, Lu 2016). The FEF located in northeastern Taiwan is the main site for long-term ecosystem research in Taiwan and an important site for global ecological researches. Whether the FEF has experienced climate changes like other parts of Taiwan is a topic which many researchers are concerned about. Long-term weather monitoring has been carried out at the FEF by the Taiwan Forestry Research Institute (TFRI) which has accumulative records of more than 30 yr. These records can be examined to determine whether and how the FEF has been affected by global warming and experienced climate change. Therefore, historical rainfall and temperature records of a weather station in the FEF, a typical weather station of hilly land in northeastern Taiwan, were examined to analyze the tendency of rainfall and temperature changes. Hopefully, the results will be useful for the effective management of water resources and ecosystems in the future.

## MATERIALS AND METHODS

### Site description

The FEF has an area of about 1097.9 ha with elevations ranging 400~1400 m. Vegetation in the FEF is a typical moist, subtropical, mixed evergreen forest of northeastern Taiwan and is mainly composed by plants of the Lauraceae and Fagaceae families. The dominant species are *Phoebe formosana*, *Litsea acuminata*, *Machilus thunbergii*, *Castanopsis cuspidata* var. *carlesii* f. *sessilis*, red nanmu, nanban Tanoak, *Neolitsea konishii*, and Konishi's newlitse (Lu et al. 2007). Soils of the forest are classified as silty loam, and in most areas, their depths do not exceed 100 cm. The Harpen creek runs through the experimental forest and empties to the southwest of the FEF. The creek has a gentle slope and an alluvial stratum in the upstream area which has significant influence on the ecosystem of the entire forest. There are 2 gauged watersheds and 3 weather stations in the FEF (Fig. 1). Weather conditions of the FEF are classified as a cool, humid subtropical climate with hot summers, cold and rainy winters, high humidity, high cloud cover, low sunshine, and weak evaporation. The distinction between the dry and wet seasons is not obvious. Detailed weather conditions are given in Table 1.

### Materials

Historical rainfall and temperature records from the Fushan nursery weather station from January 1989 to December 2020 were used as the basic materials of this study. All meteorological factors are measured every 10 min, and values of the average, maximum, minimum, and sum of the measurements of each hour are stored in a Campbell CR10 data logger Campbell Scientific Inc. and therefore all records have hourly resolution. If the rainfall amount is $\geq 0.5$ mm $d^{-1}$, then that day is considered a rainfall-day, and if the rainfall amount is $\geq 30$ mm $d^{-1}$, then that day is considered a heavy rainfall-day. There were about 40 days of missing data for the entire historical record of the studied weather station, and the missing data were imputed by substituting records from nearby weather stations or gauged in experimental watersheds (rainfall records). The priority of the replacement order of missing data was records of the aquatic plant pond weather station, Fushan no. 1 experimental watershed, and Harpen weather station. The annual average temperature, rainfall amount, rainfall-days, and heavy rainfall-days were used to examine changes in trends in this report.

### Mann-Kendall (M-K) trend test

The M-K trend test (also called the M-K test) is used to statistically assess if there is a consistently monotonic upward or downward trend in a variable of interest over time. For a time series $t_1$, $t_2$, ….. $t_n$ and its corresponding

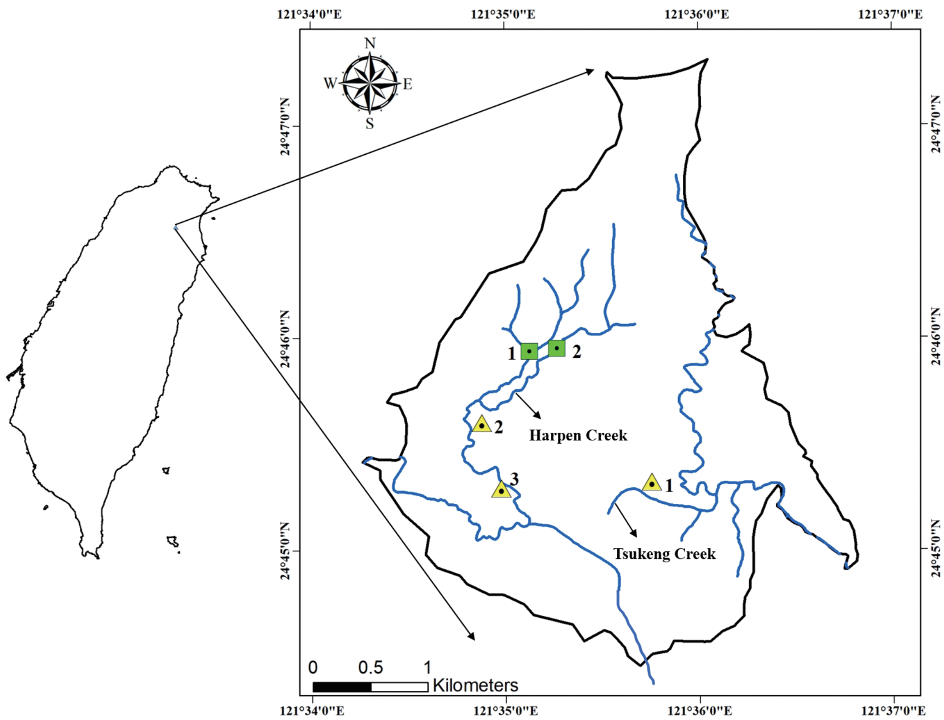


**Fig. 1. Location of the FEF (Δ1 Nursery weather station, Δ2 Aquatic pond weather station, Δ3 Harpen weather station, □1 weir of no. 1 experimental watershed, □2 weir of no. 2 experimental watershed).**

records of $x_1$, $x_2$, …….$x_n$, then the M-K statistic, $S$, is (Hamed and Rao 1998):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(x_i - x_j),\ sgn\,(x_i - x_j) = \begin{cases} +1 & x_i - x_j > 0 \\ 0 & x_i - x_j = 0 \\ -1 & x_i - x_j < 0 \end{cases};\ \dots\dots\dots \ (1)$$

where $n$ is the sample size. When $n$ is ≥ 10, the $S$ statistic approximately follows a normal distribution with the mean equal to 0 and the variance as:

$$Var\,(S) = \frac{n(n-1)\,(2n+5) - \sum_{i=1}^{m} t_i\,(t_i-1)\,(2t_i+5)}{18};\ \dots\dots\dots \ (2)$$

where m is the number of the group of tied data, and $t_i$ is the number of tied data of each group. However, there are nearly no tied data for meteorological and hydrological records, and the above equation can be simplified to:

$$Var\,(S) = \frac{n(n-1)\,(2n+5)}{18};\ \dots\dots\dots \ (3)$$

The M-K statistic, $Z_{MK}$, is defined as:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var\,(S)}} & S < 0 \end{cases};\ \dots\dots\dots \ (4)$$

The value of $Z_{MK}$ is used to determine whether series data have a significant trend of change or not. When $|Z_{MK}| > Z_{\alpha/2}$, then the time series has a significant change trend, and a positive S value indicates an upward trend, and a negative value, a downward trend. α is the significance level. A 5% significance level was selected in this report, and $Z_{\alpha/2} = 1.96$. Therefore, $Z_{MK} > 1.96$ indicates that there was a significant upward trend and $Z_{MK} < -1.96$ indicates that

**Table 1. Climatic conditions of the FEForest (January 1989~December 2020)**

| | Total rainfall (mm) | Average rainfall days (d) | Average daily temp. (℃) | Average daily max. temp (℃) | Average daily min. temp (℃) | Average relative humidity (%) | Average radiation (MJ $m^{-2}$) | Average daily wind velocity (m $s^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| Jan. | 208.7 | 20.0 | 11.8 | 15.2 | 9.2 | 94.0 | 177.94 | 1.32 |
| Feb. | 202.5 | 18.8 | 12.6 | 16.5 | 9.7 | 94.6 | 192.61 | 1.29 |
| Mar. | 170.7 | 19.3 | 14.5 | 18.7 | 11.3 | 93.4 | 277.56 | 1.29 |
| Apr. | 194.8 | 18.1 | 17.6 | 21.6 | 14.1 | 93.8 | 313.12 | 1.22 |
| May | 329.9 | 20.5 | 20.4 | 24.7 | 17.2 | 94.3 | 359.82 | 1.16 |
| June | 316.2 | 18.3 | 23.0 | 27.7 | 19.7 | 93.8 | 405.01 | 1.26 |
| July | 338.3 | 12.9 | 24.2 | 29.2 | 20.5 | 91.1 | 520.35 | 1.65 |
| Aug. | 484.0 | 15.5 | 23.9 | 28.6 | 20.5 | 91.8 | 474.15 | 1.68 |
| Sept. | 642.5 | 17.8 | 22.0 | 26.1 | 19.2 | 92.8 | 340.87 | 1.72 |
| Oct. | 515.2 | 19.3 | 18.8 | 22.1 | 16.4 | 94.7 | 229.58 | 1.37 |
| Nov. | 383.6 | 21.0 | 16.5 | 19.4 | 13.9 | 95.6 | 175.32 | 1.21 |
| Dec. | 291.3 | 20.8 | 13.1 | 16.2 | 10.6 | 94.4 | 155.00 | 1.22 |
| Avg. | | | 18.2 | 22.2 | 15.2 | 93.7 | | 1.37 |
| Total | 4077.5 | 222.4 | | | | | 3621.33 | |

temp., temperature; max., maximum; min., minimum, Avg., average.

there was a significant downward trend.

### Anomaly analysis

The difference between the value of a particular variable and its average value is called an anomaly. Rainfall and temperature records of the FEF were first tested for outliers to eliminate any unreasonable records from the dataset. Any record greater than the high outlier or less than the low outlier was considered to be an unreasonable record, and the procedures for calculating the higher and lower outliners are described by the US Water Resources Council (1981). The annual rainfall total and average temperatures were calculated, and the anomaly was obtained by the difference in the annual average amount and the average of the entire dataset. Then departure diagrams were drawn to compare patterns of shifts and differences to illustrate the trends of change through time.

## RESULTS

### Long-term changes in rainfall

Long-term changes in annual rainfall, rainfall-days, and heavy rainfall-days during the period from 1989 to 2020 in the FEF are shown in Fig. 2. Values of the M-K trend test ($Z_{MK}$) for the series records of the annual rainfall amount, rainfall-days, and heavy rainfall-days were 0.088 ($S$ = 64, VAR($S$) = 68448.00), 2.644 ($S$ = 164, Var($S$) = 3800.67), and 0.840 ($S$ = 55, Var($S$) = 4128.67), respectively. The M-K statistics indicated that the annual rainfall amount, rainfall-days, and heavy rainfall-days all had upward trends. Among them, only annual rainfall-days reached a significant level during the past 32 yr.

Departure diagrams of the rainfall amount indicate that the annual rainfall slightly increased during the test period in the FEF. Rainfall amounts showed great fluctuations from year to year (annual rainfall ranging

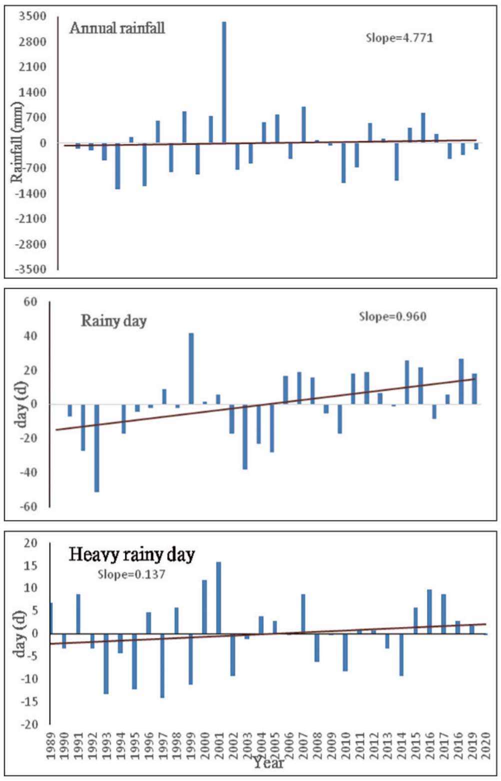


**Fig. 2. Long-term trends of annual rainfall amount, rainfall-days, and heavy rainfall-days in the FEF.**

2840.5~7436.5 mm) with an increasing rate of about 47.7 mm decade$^{-1}$. Long-term changes in rainfall-days showed a steady and significant increasing tendency from 1989 to 2020 in the study area with a rate of about 9.6 d decade$^{-1}$. It was noted that rainfall-days obviously increased after 2006. The change point detected using the Mann-Whitney-Pettit test also revealed that the possibility of change in that year was as high as 0.96 (Pettit 1979) which confirmed the conversion. The number of heavy rainfall-days also showed an increasing tendency. This phenomenon indicated that large storms occurred more frequently, and rainfall was more concentrated in recent years. Due to the frequencies of both rainfall-days and heavy rainfall-days having increased in the last 3 decades, rainfall amounts also increased.

### Long-term changes in temperature

The annual average temperature and average temperatures of the coldest (January) and hottest (July) months were selected to examine trends of change in temperature in the FEF. The anomaly diagrams are shown in Fig. 3. Values of $Z_{MK}$ for the series of annual average temperature, and averages of January and July temperatures were -2.903 ($S$ = -180, VAR($S$) = 3802.67), -1.314 ($S$ = -82, Var($S$) = 3081.67), and -2.822 ($S$ = -175, Var($S$) = 3081.67), respectively. Results indicated that temperature in the FEF showed a downward changing trend for all tested time series records, and among them, the change trends of the annual average temperature and July average temperature reached the 95% significance level. The annual average temperature in the FEF ranges 17.24~20.47℃, with an average of 18.23℃. It showed a significant decreasing trend due to a large temperature decrease in summer. The decreasing rate for the annual average temperature was about 0.4℃ decade$^{-1}$, and those for the average temperatures in January and July were about 0.4 and 0.6℃ decade$^{-1}$, respectively. Whether decreasing temperatures will influence the ecosystem of the FEF is another topic that needs to be studied.

## DISCUSSION

### Rainfall characteristics in the FEF

Characteristics of rainfall in the FEF can be appropriately described as plentiful and evenly distributed throughout the year. There are a lot of both the rainfall amount and rainfall-days. The average annual rainfall exceeds 4000 mm which is about 1500 mm more than the average annual rainfall of Taiwan as a whole. The number of rainfall-days in a year

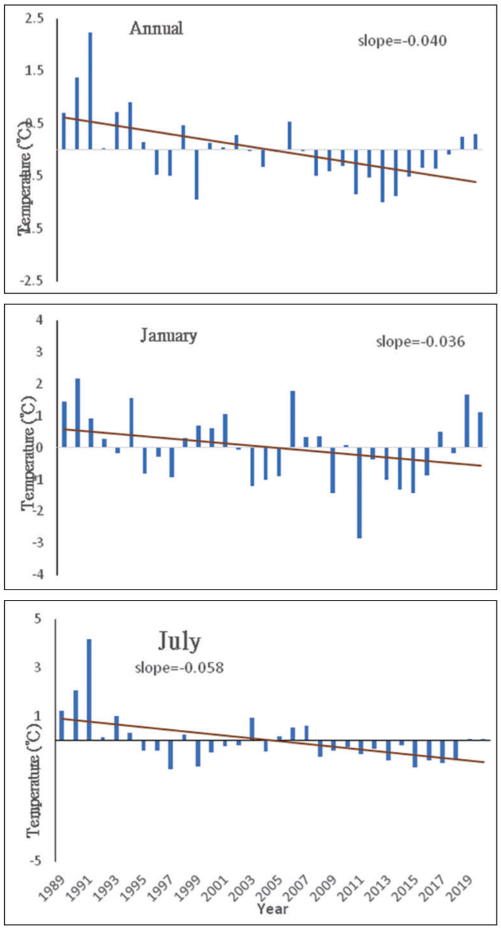


**Fig. 3. Long-term trends of the annual average, and average temperatures in January and July for the FEF.**

is as high as 220 d, which is certainly within the highest top 10 records among all rainfall stations in Taiwan. The abundant and evenly timed distribution of rainfall is attributed to the location and topographic conditions. The FEF is located on the western edge of the Lanyang Plain which is surrounded by mountains on 3 sides, and the other side faces the Pacific Ocean. The entire Lanyang Plain is located on the main path of the northeast monsoon, and the FEF is on the windward side of the northeast monsoon. In addition to the abundant rainfall brought by the northeasterly monsoon, rainfall from other mechanisms also occurs here, so rainfall in the FEF is particularly abundant.

Rainfall mechanisms in the FEF can be classified as frontal rain, thunderstorms, and typhoon rain. During the cold season (generally October to April), when the northeasterly monsoon brings enough moisture, then there will generally be small to moderate continuous rainfall in the area. During the *mei-yu* (plum rain) season (generally from 15 May to 15 June), frontal systems from southern China and convective systems embedded in the southwesterly monsoon flow frequently bring heavy precipitation to the entire island including the FEF (Yeh and Chen 1998, Chen and Chen 2003). Frontal systems commonly bring heavy rainfall to this area during the *mei-yu* season. There is hot weather over all of Taiwan after the mei-yu season, and thunderstorms are prone to occur due to strong convection in the afternoons. The beginning of thunderstorm activities in the FEF area generally occurs in May, and the abundant rainfall amounts brought by thunderstorms are responsible for the second largest annual rainfall peak during the period from June to August. About 3.6 typhoons per year hit Taiwan on average, and cause heavy rainfall over the area as they move across (Shieh et al. 1998). The top 2 highest daily rainfall records (680.5 and 580.0 mm $d^{-1}$) in historical records of the FEF occurred on September 18, 2001 and August 26, 2004 which were respectively associated with Typhoons Nari and Aere. Typhoon rainfall is a disaster-causing rainfall pattern in this area.

On average, there are a total of 222.4 d which have at least 0.5 mm $d^{-1}$ of rainfall in the yearly cycle of the FEF. Rainfall-days are more evenly distributed throughout the year. Rainfall in the FEF in July and August mostly comes from thunderstorms if there is no typhoon, so there are fewer rainfall-days in those 2 mon. The higher number of heavy rainfall-days in the historical database almost all occurred in May, June, September, and October (their averages exceed 4.5 d). Heavy rainfall in May and June is brought by *mei-yu*, and that in September and October is brought by typhoons and the northeasterly monsoon. Rainfall in other periods is mostly associated with the monsoon which is generally of a moderate intensity but lasts a long time.

The rainfall amount, the number of rainfall-days, and the number of heavy rainfall-days in the FEF showed an increasing trend over time. The increasing rainfall trend is consistent with the increasing rainfall trend in northern Taiwan. The global warming phenomenon has caused Taiwan's rainfall belt to continually move northward, and rainfall and rainfall-days in the northern region have continued to increase in recent years (Lu et al. 2012). Results of this report further confirmed this phenomenon. The increasingly uneven distribution of rainfall in space and time in Taiwan is unfavorable for water resources management.

**Reasons for the temperature decline in the FEF**

Affected by global warming, average temperatures in many places around the world have been rising year by year (Ramanathan and Carmichael 2008, IPCC 2013). Lu et al. (2012) indicated that the average temperature in low-elevation areas of Taiwan increased by about 1.4℃ in the period of 1911 to 2009. However, temperature records of the FEF showed that the temperature did not rise but had a decreasing change tendency. The decreasing tendency was reflected in temperatures in both summer and winter. Possible reasons for the declining changes are due to effects of extreme temperatures and the increasing numbers of rainfall-days. The greenhouse effect causes more energy to be stored in the atmosphere, and the forces that drive the movement of moisture and air have greatly increased. Therefore many places are experiencing more occurrences of extreme temperatures, and the FEF is no exception. If we consider the distribution of daily air temperature to be normal and the quantities of corresponding accumulative probability of $< 2.5\%$ or $> 97.5\%$ to be treated as extreme events, then the threshold for an extremely low temperature in the FEF is about 5.34℃. The numbers of occurrences of extremely low temperatures in 5-yr intervals from 1990 to 2020 were 3, 2, 3, 9, 11, and 13, respectively. This phenomenon indicates that the occurrence of unusually low temperature in winter occurred more frequently recently than before, and caused the average temperature in winter to decrease.

Another reason for the temperature decline is the increasing number of rainfall-days. Rainy days generally have high humidity and low solar radiation, so the temperature is lower than on non-rainy days. Statistical analysis of all historical records of the Fushan nursery station indicated that the range of average monthly difference in daily air temperatures between sunny and rainy days is -0.396~2.143℃ with an average of about 1.060℃. The lower average daily temperature for sunny days occurred in January when the radiant cooling effect is strong. However, these situations were not universal, and its influence on the annual average temperature was minor. It can be confirmed that the increasing number of rainy days is the reason for the decrease in temperature in the FEF. Attributable to increased cloud cover, daytime temperatures were relatively lower in summer in the last 2 decades in the FEF. The lower daytime temperatures also caused the difference in temperature between day and night to decrease (Lu and Hwang 2013). This phenomenon caused the average monthly temperature to decrease in summertime. The average July temperate in the FEF is 24.20℃ with a range of 23.01~28.39℃. However, the average temperature in July never exceeded 25.0℃ since 2003. The same situation also occurred in August. The decreasing temperature in summer also caused a reduction in the annual average temperature. Although there was no significant increase in rainfall-days in summertime, the significant increase in the number of rainfall-days throughout the year indirectly caused the temperature to decrease.

It is an indisputable fact that global warming has increased temperatures around the world. The climate change phenomenon in Taiwan is part of a large-scale warming system in East Asia, rather than a local phenomenon. However, due to differences in geographical conditions, different degrees of warming are certain to appear, and the opposite situation may still occur in some small local areas. Meteorological factors change more drastically in small areas because of the terrain and geographic location. The situation of the temperature not increasing but decreasing in the FEF is related to its geographical conditions and changes in meteorological factors. The increase in rainfall and the greater frequency of extreme temperatures are the primary reasons for the decrease in temperature in the FEF. Whether this phenomenon is occurring in other parts of the northeastern corner of Taiwan is a topic worthy of investigation.

## CONCLUSIONS

The rainfall amount, the number of rainfall-days, and the number of heavy rainfall-days in the FEF all showed increasing trends during the past 32 years. The increases in the rainfall amounts, rainfall-days, and heavy rainfall-days were about 47.71 mm decade$^{-1}$, 9.60 d decade$^{-1}$, and 1.37 d decade$^{-1}$, respectively. Among them the changing trend of rainfall-days reached the 95% confidence level, which indicated the changing trend was significant. Due to the upward trends of rainfall amounts and rainfall-days and more frequently occurring unusual lower temperatures, temperatures in the FEF show decreasing tendencies for both summer and winter temperatures. The decreasing rates were about 0.40, 0.36, and 0.58℃ decade$^{-1}$ for the annual average, average January temperature, and average July temperature, respectively. The phenomenon that temperature in the FEF did not increase but decrease is related to its terrain and geographic location. Those 2 factors create favorable rainfall conditions, and the increasing rainfall indirectly caused the temperature to decrease in the last 3 decades.

## ACKNOWLEDGEMENTS

Personnel at the Fushan Research Center who are responsible for the maintenance of the weather stations and gauged watersheds are Mr. Wu Yin-Wang and Mr. Weng Der-Chuan. They are the greatest contributors behind the scenes. We would like to express our sincere appreciation and highest respect for their work.

## LITERATURE CITED

**Chen CS, Chen YL. 2003.** The rainfall characteristics of Taiwan. Am Meteor Soc 131:1323-41.

**Chen YL. 2008.** Taiwan's climate change over a century. Sci Develop (424):6-11. [in Chinese].

**Hamed KH, Rao AR. 1998.** A modified Mann-Kendall trend test for autocorrelated

data. J Hydrol 204:182-96.[?]
**Hsu HH, Chen CT. 2002.** Observed and projected climate change in Taiwan. Meteorol Atmos Phys 79:87-104.
**IPCC. 2013.** Climate change 2013: the physical science basis. Cambridge, UK: Cambridge Univ. Press.
**Lu EY, Liu YY, Yen CH. 2007.** Dynamics of foliar nutrients in major species of a broadleaf forest in the Fushan Experimental Forest, northeastern Taiwan. J For Sci 22(3):307-19.
**Lu MM, Cho YM, Lee SY, Lee CT, Lin YC. 2012.** Climate variations in Taiwan duration 1911-2009. Atmosph Sci 40(3):297-321.
**Lu SY. 2016.** Study of rainfall characteristics and their changes on the Hengchun Peninsula. J For Sci 31(1):49-60.
**Lu SY, Huang HH. 2013.** Characteristics of climatic conditions and its change trends of the Fushan Experimental Forest. TFRI, For Res Newsl 20(6):69-73. [in Chinese].
**Pettit AN. 1979.** A non-parametric approach to the change point problem. J Appl Stat 28(2):126-35.
**Ramanathan V, Carmichael G. 2008.** Global and regional climate changes due to black carbon. Nat Geosci 1:221-7.
**Shieh LS, Wang ST, Cheng MD, Yeh TC. 1998.** Tropical cyclone tracks over Taiwan from 1897 to 1996 and their applications. Taipei, Taiwan: Central Weather Bureau Technical Report CWB86-1 M-01. 497 p.
**U.S. Water Resources Council 1981.** Guidelines for determining flood frequency. Bulletin 17B. Reston, VA: U.S. Geological Survey.
**Wang CH. 2004.** Precipitation changes and their impacts on the water resources management in Taiwan. Proceedings of International Symposium on Hydrogeological Investigation and Remedial Technology, 15~16 November 2004. Jhongli, Taiwan: National Central Univ. p 176-90.
**Wang CH, Lin WZ, Peng TR, Tsai HC. 2008.** Temperature and hydrological variations of the urban environment in the Taipei metropolitan area, Taiwan. STOTEN (Sciences of Total Environment) 404:393-400 DOI: 0.1016/j.scitotenv.2008.04.020.
**Wu YC, Chen YM, Chu RL. 2010.** The change trends of Taiwan's climate. NARL Q 25:40-6. [in Chinese].
**Yeh HC, Chen YL. 1998.** Characteristics of rainfall distribution over Taiwan during TAMEX. J Appl Meteor 37:1459-69.