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# Climate change induced the altering in precipitation characteristics across the rice cultivation paddies of Vietnam

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**सार** – विश्व स्तर पर, यह दावा करने के लिए पर्याप्त ठोस सबूत हैं कि वर्षण विशेषताओं (सीपीसी) में परिवर्तन का मुख्य कारक जलवायु परिवर्तिता है। इसलिए, सीपीसी का मूल्यांकन स्थानीय कृषि गतिविधियों के लिए महत्वपूर्ण है। इस अध्ययन का उद्देश्य कृषि क्षेत्र पर जलवायु परिवर्तन (आईसीसी) के प्रभावों के एक विशिष्ट मामले के रूप में वियतनाम में लॉन्ग ज़ुयेन क्वाड्रैंगल (एलएक्सक्यू) के चावल के खेतों (आरसीपी) में सीपीसी की जाँच करना है।

उद्देश्य की प्राप्ति के लिए, सबसे पहले 1978 - 2021 के दौरान एलएक्सक्यू में 9 प्रेक्षण स्टेशनों पर दैनिक वर्षण डेटा श्रृंखला का एकरूपता परीक्षण लागू करके गुणवत्ता के लिए मूल्यांकन किया गया था। दूसरे, गैर-प्राचलिक दृष्टिकोण का एक सेट लागू करके सीपीसी द्वारा मूल्यांकित वर्षण डेटा की जाँच की गई, और अंत में, अध्ययन क्षेत्र में सीपीसी के स्थानिक वितरण मानचित्रों को आर्कजीआईएस (संस्करण 10.8) सॉफ्टवेयर में एकीकृत थिएसेन बहुभुज एल्गोरिथ्म के आधार पर दर्शाया गया।

95% विश्वसनीयता स्तर के साथ, निष्कर्षों से पता चला कि तटीय कृषि योग्य भूमि के किनारों पर वार्षिक वर्षा और आर्द्र मौसमी वर्षा के लिए सांख्यिकीय रूप से नगण्य गिरावट की प्रवृत्ति दर्ज की गई, जबकि उत्तर-पूर्व से दक्षिण-पूर्व भाग में आरसीपी के साथ सांख्यिकीय रूप से नगण्यबढ़त की प्रवृत्ति का पाई गई। अध्ययन के परिणामों में उल्लेखनीय विशेषता यह है कि शुष्क मौसम में वर्षा के लिए सांख्यिकीय रूप से नगण्य अपट्रेंड (ZMK = 0.043 ~ 0.126) देखा गया। ये निष्कर्ष ग्रीष्म-शरद ऋतु की फसल के मौसम के दौरान कृषि गतिविधियों में सकारात्मक योगदान दे सकते हैं।

**ABSTRACT.** Globally, it has enough convincing evidence to assert that climate variability is the main factor causing the change in precipitation characteristics (CPCs). Appraising the CPCs is, therefore, crucial for local agricultural activities. The aim of this study is to investigate the CPCs across the rice cultivation paddies (RCPs) of the Long Xuyen Quadrangle (LXQ) in Vietnam as a typical case of the impacts of climate change (ICC) on the agricultural sector.

To achieve the intended objective, firstly daily precipitation data series at 9 observation stations across the LXQ throughout 1978 - 2021 were appraised for quality by applying the homogeneity tests. Secondly, appraised precipitation data were investigated the CPCs applying a set of non-parametric approaches, and finally, the spatial distribution maps of the CPCs across the study area were shown off based on the Thiessen polygon algorithm integrated into the ArcGIS (Version 10.8) software.

With a 95% confidence level, the findings revealed that a statistically insignificant downward trend for annual precipitation and wet seasonal precipitation was recorded along the coastal arable land edges while the statistically insignificant upward trend was detected along the RCPs in the northeast to southeast part. One striking feature the study results revealed is that a statistically insignificant uptrend (ZMK = 0.043 ~ 0.126) was observed for precipitation in the dry season. The findings could contribute positively to agricultural activities during the summer-autumn crop season.

**Key words**– Buishand test, Climate change, Precipitation, Rice paddies, Trend.

## 1. Introduction

In recent decades, climate change has caused numerous challenges for aspects of life and is the subject of special attention of mankind in the 21st century (Bartels *et al*., 2020; Westra *et al*., 2012). According to Alhathloul *et al*. (2021), climate change and anthropogenic have caused serious effects on the aspects of the living environment, leading to the increase (*e.g*., intensity, frequency, and duration) of extreme climate events (ECEs). The ECEs are recognized as a key cause of reducing crop yields over the world (Banerjee *et al*., 2020; IPCC, 2014). Studies on the relationship between climate change with the trend of ECEs have stated that the increasing trend of extreme precipitation events (EPEs) is dominant in many parts of the world (Meshram *et al*., 2017; Westra *et al*., 2012) while the decreasing tend of EPEs is stated the main cause, leading to the increasing occurrence of meteorological drought (Chen *et al*., 2020; Marie *et al*., 2021). Accordingly, precipitation is considered a typical climate variable that a binding links to aspects of life and most notably the agricultural sector (Nikumbh *et al*., 2019, Panda and Sahu, 2019). The CPCs lead to, therefore, certain influences on various aspects of life especially the agricultural sector (Daksiya *et al*., 2017; Lee and Dang, 2019). IPCC (2014) reported that the unusual increasing/decreasing tends of ECEs are negatively affecting various socio-economic sectors. Therefore, studies on the CPCs in relation to the EPEs have received the attention of specialized scientists (AlSubih *et al*., 2021; Chen *et al*., 2020).

As a recognition of the importance role of precipitation for agriculture sector, studies on the CPCs in relation to the ICC have been commonly deployed in the large cultivation regions around the world (Ali *et al*., 2021; Espinosa *et al*., 2021). For instance, Wu *et al*. (2017) conducted a study on CPCs in Shaanxi, China using the Mann-Kendall test and linear regression method and reported a significant decreasing tend recorded in the Wei River Basin. In India, Gupta *et al*. (2021) analysed the spatiotemporal tends of the CPCs across the Jharkhand region. Their results pointed out that a significant decreasing trend approximately of 0.0003-0.0012 mm/year was detected for AP. In 2019, Iqbal *et al*. investigated the spatial distribution of the CPCs in the sub-Himalayan region based on the modified Mann-Kendall test and reported that insignificant change tend is recorded in the AP. In Saudi Arabia, AlSubih *et al*. (2021) investigated the spatiotemporal tends of climatic variables across the Aseer region under the ICC by applying the modified Mann-Kendall test and the Theil-Sen approach. They reported that along the Northwest to Southwest edges recorded no exhibit significant tend.

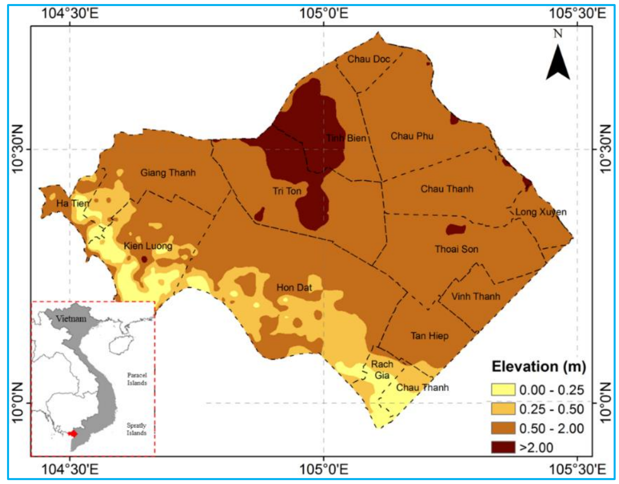



**Fig. 1.** Topographic map of the the Long Xuyen Quadrangle

The LXQ is known a rice cultivation delta belonging in the Mekong Delta of Vietnam with a total annual rice production of up to five million tons, contributing to maintaining Vietnam's position as one of the top three rice exporters in the world (Lee and Dang, 2018; Nguyen *et al*., 2022). However, the area is currently facing challenges such as salt intrusion along the edges of low-lying coastal arable land due to sea level rise and drought due to precipitation decline resulting in a lack of irrigation water (IPCC, 2014; Lee and Dang, 2019). These adverse effects are an inevitable consequence of ICC (Dang *et al*., 2021; Lee and Dang, 2019). In order to enhance farmers' understanding as well as contribute to adaptation to the ICC, the study is focused to investigate the CPCs across the LXQ, as a typical study case of the ICC on agricultural productivity activities.

## 2. Materials and method

### 2.1. *Study area*

The LXQ is located in the northwest of the Mekong Delta (09° 57' - 10° 42' N latitudes and 104° 29' -105° 29' E longitudes), stretching a part of the area of three provinces of An Giang, KienGiang and Can Tho (Fig. 1) with the total land area of approximately 470000 ha (Lee and Dang, 2018). The LXQ is dominated throughout the year by the two major monsoon regimes including the northeast monsoon and the southwest monsoon (Lee and Dang, 2019). The dry season commonly coincides with a period of prevailing activity of the northeast monsoon (November to April) and is characterized by dry weather, hot and little precipitation while the wet season often coincides with a period of prevailing activity of the southwest monsoon circulation

**TABLE 1**

**Basic information about precipitation observation stations across the study area**

| No. | Station | Longitude(E) | Latitude(N) | Altitude(m) | Record period |
|---|---|---|---|---|---|
| 1 | Chau Doc | 105° 04' 12 | 10° 25' 12 | 0.76 | 1978-2021 |
| 2 | Xuan To | 104° 56' 44 | 10° 35' 32 | 1.56 | 1992-2015 |
| 3 | Tri Ton | 105° 01' 48 | 10° 15' 36 | 1.74 | 1983-2015 |
| 4 | Long Xuyen | 105° 25' 13 | 10° 22' 21 | 0.78 | 1979-2021 |
| 5 | RachGia | 105° 12' 01 | 09° 54' 23 | 0.27 | 1983-2021 |
| 6 | Tan Hiep | 105° 09' 00 | 10° 30' 00 | 0.58 | 1983-2015 |
| 7 | Ha Tien | 105° 30' 00 | 10° 22' 12 | 0.32 | 1981-2021 |
| 8 | KienLuong | 104° 38' 07 | 10° 18' 15 | 0.43 | 1986-2021 |
| 9 | Can Tho | 105° 28' 01 | 10° 01' 01 | 0.67 | 1978-2021 |

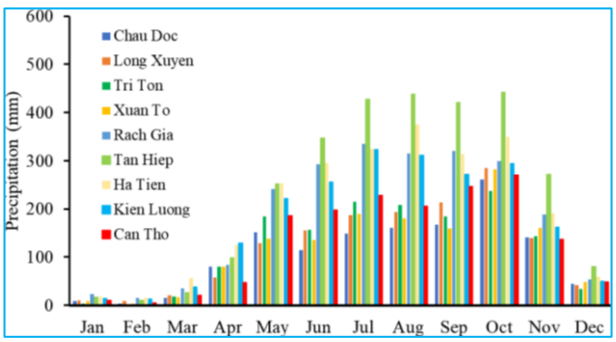



**Fig. 2.** Distribution of monthly precipitation across the study area during the period 1978-2021

(May to September) and characterized by wet, cool and high precipitation. Annually, the area receives precipitation of around 1500 mm with proportionally 10% of the total precipitation volume concentrated in the dry season (Fig. 2).

The topography along the low coastal arable edges in range from 0.25 to 0.75 m a.m.s.l. is one of the main causes, leading to the potential risks of salt intrusion due to sea level rise and drought due to precipitation decline (IPCC, 2014; Nguyen *et al*., 2022). These two key factors are adversely affecting farmer's cultivation activities (Lee and Dang, 2019). Currently, the LXQ frequently undergone from severe drought events lead to lack of irrigation water for agricultural production (IPCC, 2014; Lee and Dang, 2018).

### 2.2. *Data collection and quality verification procedures*

To deploy the research, daily precipitation data at 9 observation stations across the LXQ (Fig. 1 and Table 1) were collected from National Centre for Hydro-meteorological Forecasting (NCHMF) during the period 1978-2021. Firstly, precipitation data series at all observation stations are quality appraised based on XLSTAT software. Secondly, the required precipitation data will be used for monotonic trend detection. Finally, the CPCs will be mapped on the spatial distribution through ArcGIS software (Version 10.8).

### 2.3. *Approach methods*

#### 2.3.1. *Approach for detecting interruption points*

Changes caused by subjective (*e.g*., relocation of observation stations, measurement method changes) and objective reasons such as damaged equipment and disasters can lead to the quality of the long-term observation data series no longer being guaranteed (Bickici and Kahya, 2019; Dang, 2022). As a consequence, studies on applying heterogeneous data series can lead to incorrect conclusions. It is, therefore, essential to verify the quality of data series through homogenous analysis before applying them to further studies (Bickici and Kahya, 2019; Patakamuri *et al*., 2020). In this research, the two tests namely the Buishand and Pettitt are selected to verify the homogeneity of the precipitation data series across the LXQ.

The Buishand test is known as a statistical method that is commonly applied to detect the cumulative deviation from the mean for the purpose of homogeneity analysis of any data series. Buishand test assumes that the input data series has the form of a normal distribution, and they are distributed independently and randomly based on the $H_0$null hypothesis. Buishand test is relatively sensitive in detecting breaks in the middle of the data series.

$$S_0^* = 0; S_k^* = \sum_{i=1}^{k}\left(y_i - \bar{y}\right) \qquad k = 1,\ldots,n \tag{1}$$

where $y$ and $\bar{y}$ are the $i^{th}$ and mean values of the observation data series ($y_1$, $y_2$,…, $y_N$), and $k$ is the number of the data which is detected break point.

Accordingly, an adjusted partial sum is received based on dividing the $S_k^*$ by the sample standard deviation.

$$S_k^{**} = \frac{S_k^*}{\sqrt{\frac{\sum_{i=1}^{k}\left(y_i - \bar{y}\right)}{N}}} \text{ with } k = 1,\ldots,n \tag{2}$$

Accordingly, if the observed data series is homogeneous, the $S_k^*$ value will fluctuate around 0 because there is no systematic deviation of the $y_i$ value from the mean value. If there is a "break" at the $k^{th}$ value, then the $S_k^*$ value reaches a maximum or minimum around the $k$= K point (Patakamuri *et al.*, 2020). When the statistic (Q) is applied to define homogeneity:

$$Q = \max_{0 \le k \le N}\left|S_k^{**}\right| \tag{3}$$

Pettitt's is known as a nonparametric test for randomness which was designed to detect the point of change in the hydrometeorological and environmental data series (Dinh and Dang, 2022). In the Pettitt test, the $H_0$ null hypothesis points out the independent and random distribution of the input data series while the alternative hypothesis points out a sudden change. By assuming the data series are ranked from $r_1,\ldots,r_n$ of $X_1,\ldots$, Xn, Pettitt's test defines the value of $X_k$ as follows:

$$X_k = 2\sum_{i=1}^{k} r_i - k(n+1),\; k = 1, 2, 3, \ldots\ldots, n \tag{4}$$

If the data series are breaked in the $k^{th}$ year, the statistic is maximal or minimal reach the year $k$ = K.

$$X_K = \max_{1 \le k \le n}\left|X_K\right| \tag{5}$$

The statistical significance for a probable level α is defined by (6):

$$X_{ka} = \left[\frac{-\ln a\left(n^3 + n^2\right)}{6}\right]^{\frac{1}{2}} \tag{6}$$

If the $X_K$ value is less than the critical value ($p$), the test is called the statistical significance and the $H_0$ null hypothesis is accepted. It means that the data series are homogeneous (Bickici and Kahya, 2019; Dang, 2022).

2.3.2. *Approaches for detecting monotonous tends*

We applied non-parametric statisticals such as Mann-Kendall test and Sen's slope estimator to investigate the CPCs across the LXQ. Specifically, the Mann-Kendall test was commonly applied to detect the monotonic trend of precipitation data series while Sen's slope estimator was applied to define the true slope of an existing trend (Praveen *et al.*, 2020; Islam *et al*. 2020). The Mann-Kendall test is calculated by following formula:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \mathrm{Sgn}\left(X_j - X_i\right) \tag{7}$$

$$\mathrm{Sgn}\left(X_j - X_i\right) = \begin{cases} +1 & \text{if } x_j - x_i > 0 \\ 0 & \text{if } x_j - x_i = 0 \\ -1 & \text{if } x_j - x_i < 0 \end{cases} \tag{8}$$

Where $X_j$ and $X_i$ are the $j^{th}$ and $i^{th}$ data values; $j$ and $i$ with the condition is $j>i$. If $n \geq 10$, the statistic $S$ is approximately normally distributed with the average (E) and variance (Var) are defined by formula (9) and (10):

$$E[S] = 0 \tag{9}$$

$$\mathrm{Var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{j=1}^{m} t_j\left(t_j - 1\right)\left(2t_j + 5\right)\right] \tag{10}$$

where $m$ is the number of the tied groups in the data set and $t_j$ is the number of ties to extent $j$.

The summation term in the numerator is only used if the data series contains tied values and the values of $S$ and Var (S) are given to define the statistics of standard test $Z$ as follows:

$$Z_s = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{11}$$

where $S$ in the formula (11) is calculated by formula (12).

$$\tau = \frac{S}{D} \tag{12}$$

**TABLE 2**

**Results of quality analysis of precipitation data series at observation stations across the LXQ area throughout 1978-2021**

| No. | Station | Buishand | | Pettitt | |
|---|---|---|---|---|---|
| | | Q | p-value | K | p-value |
| 1 | Chau Doc | 16.480 | 0.535 | 4123 | 0.778 |
| 2 | Xuan To | 12.524 | 0.335 | 1514 | 0.482 |
| 3 | Tri Ton | 24.690 | 0.021 | 1559 | 0.228 |
| 4 | Long Xuyen | 27.424 | 0.061 | 6996 | 0.159 |
| 5 | RachGia | 14.616 | 0.694 | 4411 | 0.942 |
| 6 | Tan Hiep | 67.851 | 0.000 | 12795 | 0.000 |
| 7 | Ha Tien | 58.231 | 0.000 | 12030 | 0.000 |
| 8 | KienLuong | 14.351 | 0.604 | 3190 | 0.782 |
| 9 | Can Tho | 12.644 | 0.847 | 3219 | 0.269 |

**TABLE 3**

**Basic statistical characteristics of precipitation data series at observation stations across the study area throughout 1978-2021**

| No. | Station | Annual | | | Wet seasonal | | | Dry seasonal | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Rainfall (mm) | SD (mm) | CV (%) | Rainfall (mm) | SD (mm) | CV (%) | Rainfall (mm) | SD (mm) | CV (%) |
| 1 | Chau Doc | 1296.1 | 92.1 | 7.6 | 1143.6 | 89.5 | 54.7 | 152.4 | 44.6 | 150.0 |
| 2 | Xuan To | 1405.2 | 89.1 | 7.5 | 1245.5 | 90.9 | 50.1 | 154.5 | 48.4 | 151.7 |
| 3 | Tri Ton | 1469.2 | 114.9 | 9.6 | 1131.1 | 131.3 | 68.9 | 138.2 | 55.7 | 201.8 |
| 4 | Long Xuyen | 1441.3 | 90.4 | 7.7 | 1144.2 | 94.8 | 50.6 | 139.8 | 45.1 | 154.4 |
| 5 | RachGia | 2203.6 | 84.5 | 7.1 | 1992.3 | 120.6 | 42.3 | 211.3 | 58.9 | 139.2 |
| 6 | Tan Hiep | 2830.6 | 97.5 | 6.8 | 2598.0 | 175.6 | 57.3 | 232.6 | 74.6 | 160.1 |
| 7 | Ha Tien | 2375.9 | 94.6 | 7.8 | 1909.8 | 174.7 | 59.0 | 275.7 | 75.1 | 140.6 |
| 8 | KienLuong | 2083.4 | 88.3 | 7.4 | 1839.4 | 127.4 | 47.4 | 224.0 | 73.8 | 151.2 |
| 9 | Can Tho | 1602.7 | 87.8 | 7.3 | 1471.1 | 92.1 | 43.8 | 131.6 | 42.4 | 156.9 |

SD-Standard deviation; CV- Coefficient of variation

and $D$ in formula (12) is calculated based on the formula (13)

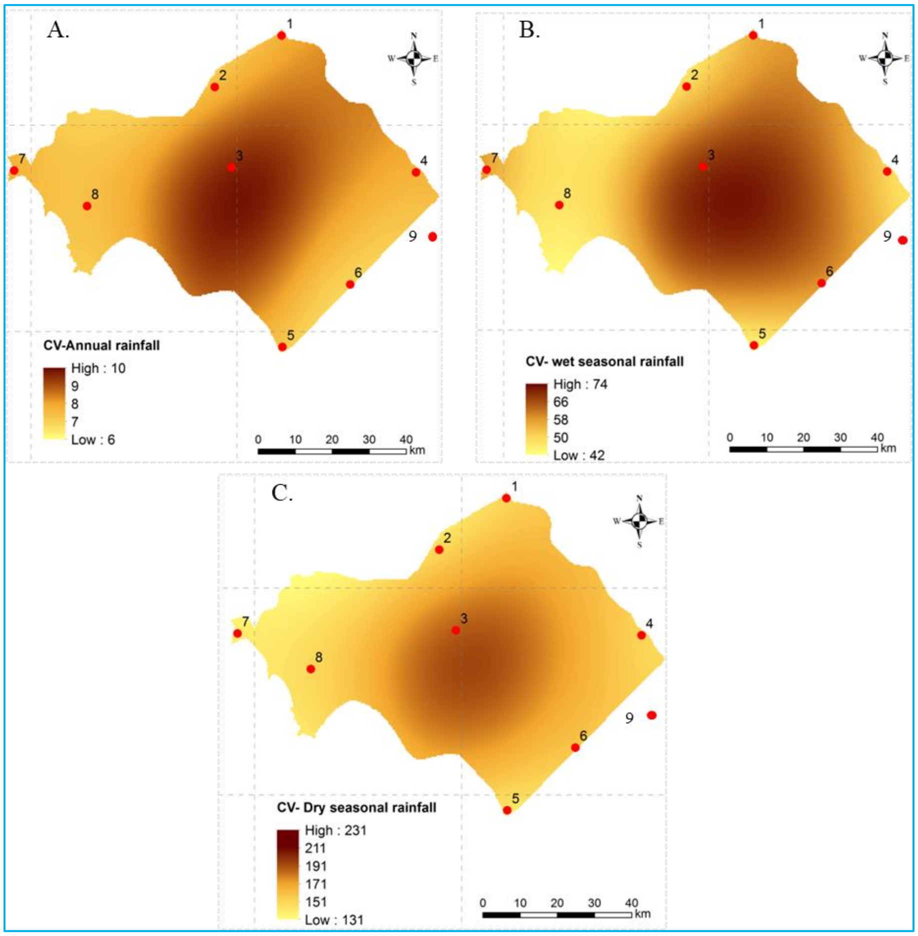
$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{m} t_j\left(t_j - 1\right)\right]^{\frac{1}{2}} \left[\frac{1}{2}n(n-1)\right]^{\frac{1}{2}} \quad (13)$$

The Sen's slope ($Z_S$) corresponds to the calculation of the median of the slopes defined on each peer of points in the data series where collected data are the regular intervals. The Sen's slope is calculated by formula (14) :

$$Z_s = \text{Median}\left(\frac{X_i - X_j}{i - j}\right) \text{with } j < i \quad (14)$$

where $X_i$, $X_j$ are data values at time scales $t_i$ and $t_j$, respectively.

In this research case, Sen's slope estimator was applied to determine the magnitude of the CPCs (Salehi *et al.*, 2020). The investigation of the CPCs across the LXQ is pointed out to identify the possible temporal changes. In this work, the 95% confidence level is applied for Mann-Kendall test and Sen's slope estimator. At the 95% confidence level (α = 0.05), the $H_0$null hypothesis of no trend is rejected if $|Z_S| > 1.96$.




**Figs. 3(a-c).** The maps of spatial distribution of the coefficient of variation of (a) annual precipitation, (b) wet seasonal rainfall and (c) dry seasonal rainfall across the study area throughout 1978-2021

## 3. Results and discussion

### 3.1. *Quality assessment of precipitation data series*

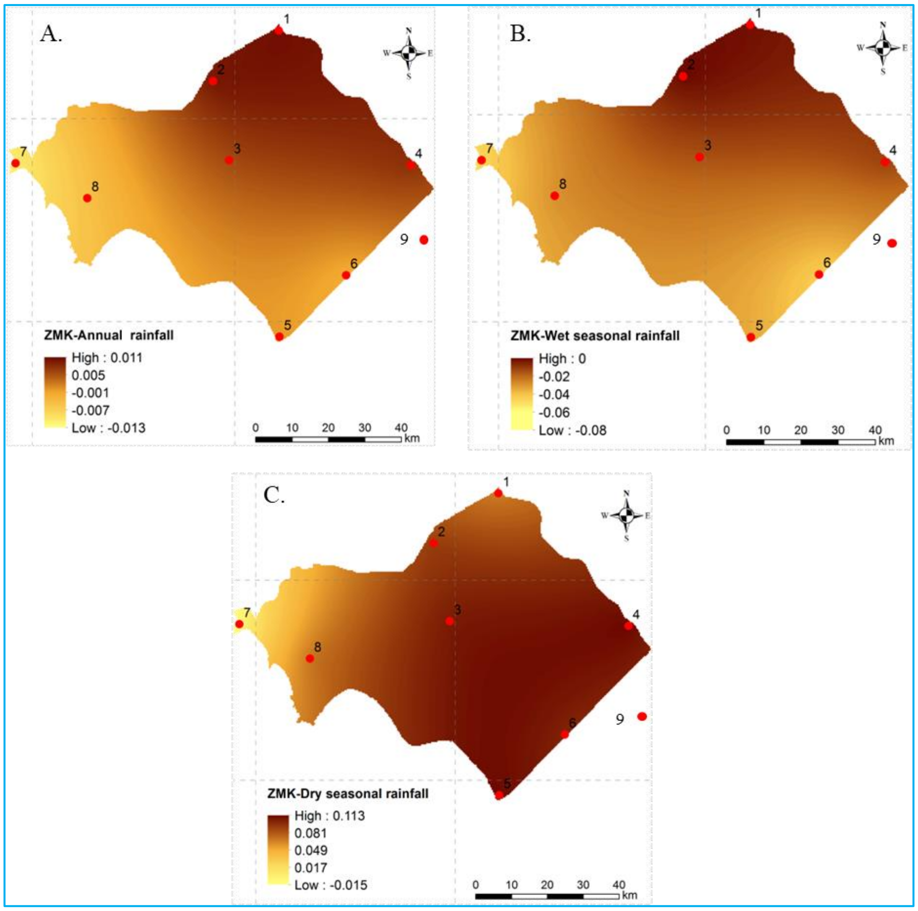
The quality of the input precipitation data series at all observation stations is appraised using the Buishand and Pettitt tests integrated in the XLSTAT software. With $\alpha = 0.05$, the results pointed out that the critical values (p) of precipitation data series at all observation stations are larger than the value of $\alpha = 0.05$ (Table 2). These revealed that precipitation data at all observation stations are of good quality and meet the requirements for further studies.

### 3.2. *Precipitation characteristics analysis*

Analysis of precipitation characteristics across the LXQ throughout 1978-2021wasgiven in Table 3. Results indicated that the average annual precipitation (AAP) over the study area is approximately of 1854.5 mm while the maximum AAP is detected up to 2830.6 mm along the western coastal edges (*e.g.*, from Rach Gia to Ha Tien cities) and the minimum AAP is recorded only 1296.1 mm in the northeastern part (*e.g.*, Chau Doc city). The standard deviation (SD) of AP is largely varied from 153.8 to 192.1 mm along the western coastal edges while the rest of the study area is slightly changed from 84.5 to 114.9 mm (Table 3).

For the coefficient of variation (CV), the CV spatial distribution of AP and seasonal precipitation including WSP and DSP across the LXQ were mapped using the Thiessen interpolation algorithm integrated into the XLSTAT software (Fig. 3).

Accordingly, the highest CV of AP was recorded in the northern part, *i.e.*, Tri Ton station (9.6%), followed by Ha Tien (7.8%) in the northwest part and Chau Doc station (7.6%) in the northeast part while the lowest CV of AP was detected along the southwest coastal edges (*e.g.*, Tan Hiep and Rach Gia stations) to southwest, *i.e.*, Kien Luong station [Fig. 3(A)]. For WSP, the highest CV was occurred in the northeastern part (Tri Ton station) up



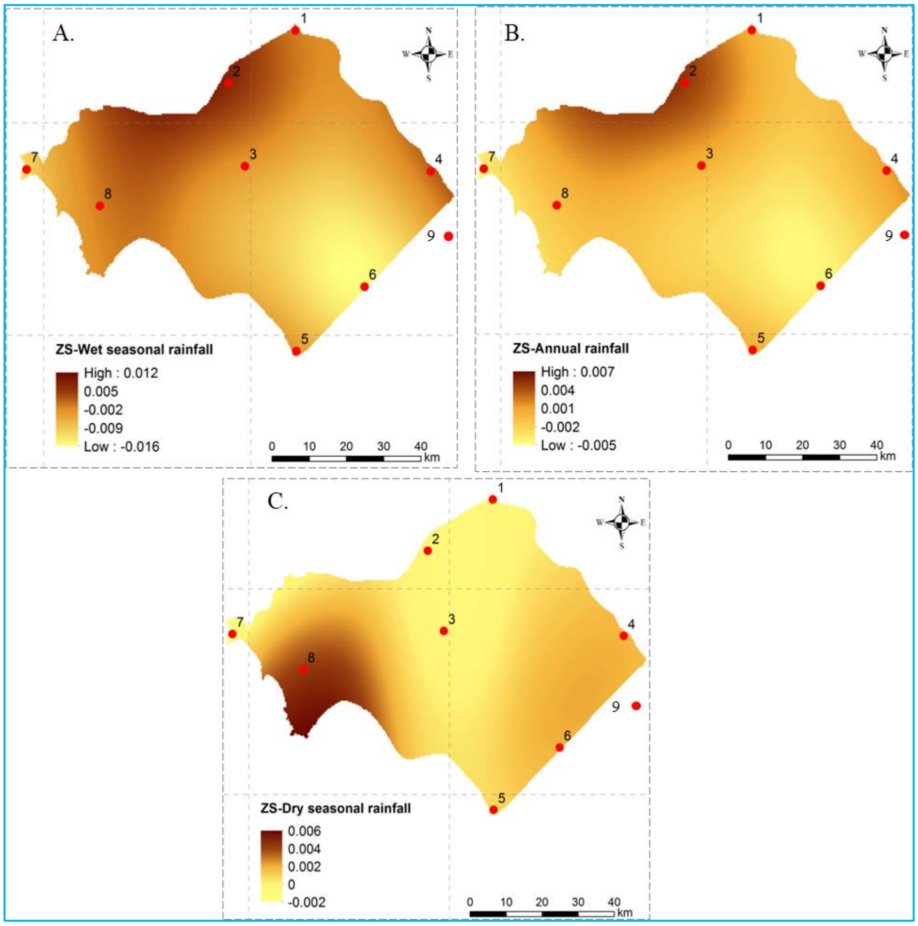

**Figs. 4(a-c).** The maps of spatial distribution of the Mann-Kendall test (ZMK) of (a) annual precipitation, (b) wet seasonal rainfall and (c) dry seasonal rainfall across the study areathroughout 1978-2021

**TABLE 4**

**Analyzed change tends of precipitation characteristics at all observation stations across the study area throughout 1978-2021**

| Station | AP | | | WSP | | | DSP | | |
|---|---|---|---|---|---|---|---|---|---|
| | $Z_{MK}$ | p | $Z_S$ | $Z_{MK}$ | p | $Z_S$ | $Z_{MK}$ | p | $Z_S$ |
| Chau Doc | 0.021 | 0.515 | 0.000 | 0.005 | 0.907 | 0.001 | 0.043 | 0.394 | 0.000 |
| Xuan To | 0.081 | 0.099 | 0.005 | 0.115 | 0.074 | 0.009 | 0.105 | 0.193 | 0.000 |
| Tri Ton | 0.011 | 0.787 | 0.000 | -0.033 | 0.526 | -0.002 | 0.109 | 0.097 | 0.000 |
| Long Xuyen | 0.063 | 0.056 | 0.001 | 0.079 | 0.057 | 0.003 | 0.126 | 0.013 | 0.002 |
| RachGia | 0.031 | 0.322 | 0.001 | 0.000 | 0.993 | 0.000 | 0.122 | 0.014 | 0.001 |
| Tan Hiep | -0.091 | 0.004 | -0.004 | -0.254 | 0.000 | -0.015 | 0.093 | 0.096 | 0.002 |
| Ha Tien | -0.104 | 0.001 | -0.005 | -0.212 | 0.000 | -0.013 | -0.059 | 0.237 | -0.001 |
| KienLuong | -0.001 | 0.046 | -0.001 | 0.025 | 0.577 | 0.001 | 0.086 | 0.114 | 0.004 |
| Can Tho | 0.002 | 0.614 | 0.001 | -0.026 | 0.523 | -0.001 | 0.072 | 0.153 | 0.000 |

ZMK: Mann-Kendall test; ZS: Sen' estimator slope and p: critical value at the 95% confidence level.




**Figs. 5(a-c).** The maps of spatial distribution of the Sen' estimator slope (ZS) of (a) annual precipitation, (b) wet seasonal rainfall and (c) dry seasonal rainfall across the study area throughout 1978-2021

to 68.9% while the lowest CV was recorded along the coastal arable edges (*i.e*., Rach Gia and Kien Luong stations) [Fig. 3(B)]. For DSP, the whole study area was recorded a strong variation with the highest CV up to 201.8% (Tri Ton station) while the lowest CV was recored approximately of 140.6% at Ha Tien station [Fig. 3(C)].

3.3. *Long-term change trends of precipitation characteristics*

Long-term change tends of precipitation characteristics including AP, WSP and DSP at 9 observation stations across the study area during the period 1978-2021 were investigated using the Mann-Kendall test (Fig. 4) and Sen's slope estimate (Fig. 5) with the 95% confidence level. For the AP, the $Z_{MK}$ values of the Mann-Kendall test vary from -1.04 to 0.081 while the critical values in ranging from 0.001 to 0.787and the $Z_S$ values of the Sen's slope estimator varying from -0.005 to 0.005 (Table 4). Specifically, with the $Z_{MK}$, p and $Z_S$ values varying from 0.002 to 0.081, 0.056 to 0.967, and 0.001 to 0.005, respectively reveals that a statistical insignificant upward trend was occurred in 6 out of 9 observation stations except for Tan Hiep, Ha Tien and Kien Luong stations. While the $Z_{MK}$-values (-0.104 ~ -0.001), the p-values (0.001 ~ 0.046), and the $Z_S$-values (-0.005 ~ -0.001) indicated a statistically insignificant downward trend of AP along the western coastal lowland edges of the study area (Fig. 4A).

For the WSP, the $Z_{MK}$, p, and $Z_S$ values varied from 0.025 to 0.115, 0.057 to 0.907 and 0.001 to 0.009 were recorded at 5 out of 9 observation stations. It implies that a statistically insignificant upward trend was detected in the mainland parts along the northern to western whereas a statistically insignificant downward trend with the values of $Z_{MK}$ (-0.254 ~ -0.026), p (0.000 ~ -0.526), and $Z_S$ (-0.015 ~ -0.001) was also detected at Tri Ton, Tan

Hiep, Ha Tien and Can Tho stations (Fig. 4B). For the DSP, a statistical insignificant upward trend with $Z_{MK}$ values varying from 0.043 to 0.126 and $Z_S$ values in the range from 0.000 to 0.004 was detected in most of the study area, except for Ha Tien station in the northwest of the study area (Fig. 4C) which detected a statistically insignificant downward trend ($Z_{MK}$ = -0.059, and $Z_S$ = -0.001).

A study result on the CPCs over the Mekong Delta by Lee and Dang (2019) revealed that a statistically insignificant upward trend was found in the DSP. According to Patakamuri *et al*. (2020), an upward trend in the DSP can positively contribute to agricultural activities where rainfed is considered as the main irrigation resource.

## 4. Conclusions

Based on the essential requirement for sustainable agricultural development, the study assessed the change trends in precipitation characteristics across the rice cultivation regions of the Long Xuyen Quadrangle, Vietnam applying 44 years (1978-2021) of long-term daily precipitation data series at nine observation stations. The results indicated that overall, the study area occurred insignificant upward/downward trends in annual and wet seasonal precipitation while only an insignificant upward trend was detected in dry season precipitation in almost observation stations. In general, ninety percent of the study area occurred a slight upward trend in the dry season precipitation. The findings revealed that the Long Xuyen Quadrangle is experiencing a period of increase in dry season precipitation, and it will contribute positively to rainfed irrigation activities, especially the summer-autumn planting crop.

*Disclaimer*: The content and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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