Trends in hydroclimatic series in Thua Thien Hue province, Vietnam: 1. Rainfall and rainy days

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Abstract

Rainfall is a good indication of the climate change impacts on water resources and changes in rainfall patterns are very important for water resources development. By utilizing the non-parametric Man-Kendall trend test and Sen's slope estimator, this paper explored the trends in 18 rainfall variables (e.g. monthly, seasonal, annual, and extreme rainfalls) and rainy days (rainfall >0 mm per day) for the period 1976-2003 at three meteorological stations (Hue, Nam Dong, A Luoi) available in Thua Thien Hue, Vietnam. This study revealed that all statistically significant trends found at 1% and 5% in the area were upward trends. A Luoi among stations and December rainfall among rainfall variables showed the most statistically significant trends. No significant trend was found in annual and seasonal rainfalls except for an upward trend in annual rainfall at A Luoi. The trend slope estimation indicated that A Luoi showed an increasing annual rainfall at the rate of 11.8% of mean per decade. In December rainfalls, the highest trend slope was found at A Luoi (45.0% of mean per decade) and the lowest one at Hue (13.0% of mean per decade). Annual rainy days increased 10 days per decade at Nam Dong. These findings provide useful references for sustainable water resources development in Thua Thien Hue.

Keywords: Trend, rainfall, rainy days, Mann-Kendall, Thua Thien Hue, Vietnam

1. Introduction

The changes in hydroclimatic variables over time are often the most important sources of information about climate change. In fact, most water resources projects are planned, designed, and operated based on the historical pattern of water availability, quality, and demand. Therefore, monitoring and interpreting changes in hydroclimatic series thus are essential for management. Rainfall is the major driving force of the land phase of the hydrological system, and changes in its pattern could have direct impacts on water resources (Kumar and Jain, 2010). Hence, rainfall is a good indication of the impacts from climate change on water resources. Increasing interest in global warming and climate changes has led to numerous trend detection studies in hydroclimatic variables, particularly in rainfall data for many areas by various authors over the world. Many authors, for example, have studied the trends and variation in rainfall over the plain of India (Basistha et al., 2007); over Turkey (Kahya and Partal, 2007); mainland Spain (Mosmann et al., 2004); over the Iberian Peninsula (Serrano et al., 1999); over North Carolina (Boyles and Raman, 2003); and many others. In contrast, there have been few trend studies for hydroclimatic variables in Vietnam. Recently, more researchers have begun paying attention to trends and variability in rainfall of Vietnam by including some stations in Vietnam in their regional-scale studies (Manton et al., 2001; Endo et al., 2009). So far, no detailed study on rainfall trends at province-scale for the Thua Thien Hue has been reported in the literature. In addition, the evidence of increased severity and frequency of recent floods and droughts (Tran, 2010) in Hue have highlighted how important it is to analyze the trends in the rainfall of this area.

The emphasis in this research is on the quantification of trends in various rainfall features at different stations in the area by utilizing the commonly-used, non-parametric Mann-Kendall trend test and Sen's slope estimator. The findings from this study provide useful references for further hydrological studies and sustainable water resources development in Thua Thien Hue.

2. Materials and methods

2.1. Materials

To take advantages of the observational data available in the region as much as possible, rainfall data sets from all three meteorological stations (Hue, Aluoi, and Namdong) as shown in Fig.1, provided by the Hydro-Meteorological Data Center of Vietnam, have been analyzed in this study. Due to the varying length of data at these stations, analysis has been performed for the common period 1976-2003 (28 years) at the three stations as the focus of the study. These data set lengths satisfy the required length in searching for evidence of climate change in hydroclimatic time-series as proposed by Burn and Elnur (2002); Kahya and Kalayci (2004). Rainfall time series at Hue station were examined not only for the common period (1976-2003), but also for the complete record 1960–2003 (41 years), separately, in order to explore the partial trends in different segments of time series.

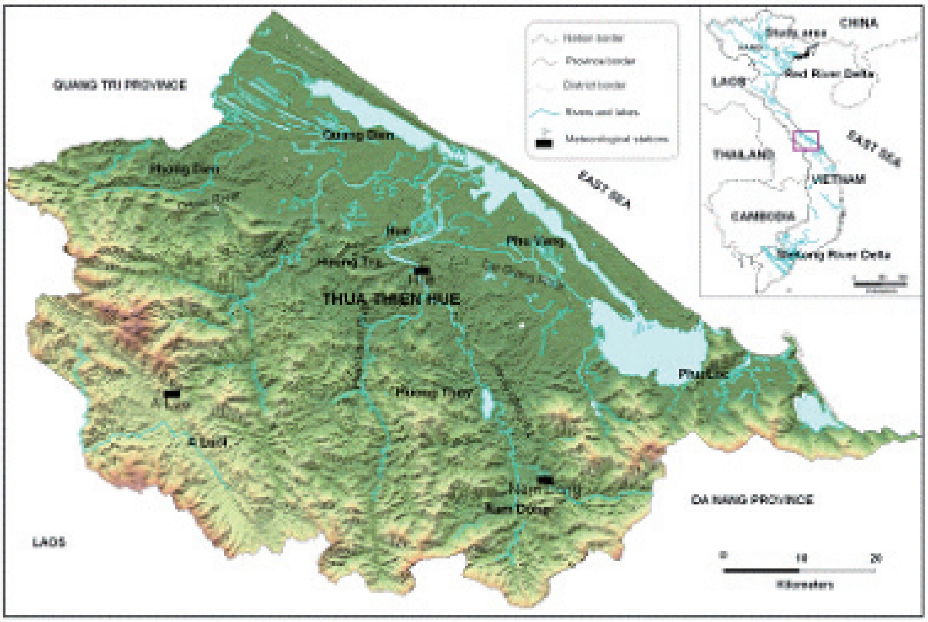


Fig. 1 Study area and distribution of meteorological stations

One of the problems in detecting and interpreting trends in hydroclimatic data is the confounding effects of serial dependence and seasonality. Hence, from original daily records as the basic data set, a total of 18 variables (monthly time series for each of 12 months of a year, annual and seasonal rainfalls, daily maximum, monthly maximum and minimum), and annual rainy days (rainfall >0 mm per day) for individual stations were computed prior to adopting the Mann–Kendall test. Analyses these variables were not only to resolve problems of serial correlation inherent in hydroclimatic time series (Boyles and Raman, 2003; Burn and Elnur, 2002; Serrano et al., 1999), but also to provide detailed and broad understandings on trends in rainfall data.

2.2. Methods

The methodologies for conducting trend analysis studies in hydroclimatic records have been comprehensively reviewed by Esterby (1998) and further reviewed by Kundzewicz and Robson (2004). Numerous trend studies referred to earlier and many others have continually highlighted the non-parametric Mann–Kendall trend test and Sen's slope estimator as excellent tools for detecting trends in hydrometeorology and environment. These method are appropriate because they allow minimal assumptions about the data, and are therefore particularly suited to hydrological series, which are often abnormally distributed and serially correlated (Kundzewicz and Robson, 2004) while being as good as their parametric competitors (Serrano et al., 1999). The methods have been employed by a number of researchers (Basistha et al., 2007; Endo et al., 2009; Endo et al., 2009) to identify the trend in hydroclimatic variables. In the present study, they were also applied to determine monotonic trends in different variables of rainfall.

3. Results and discussion

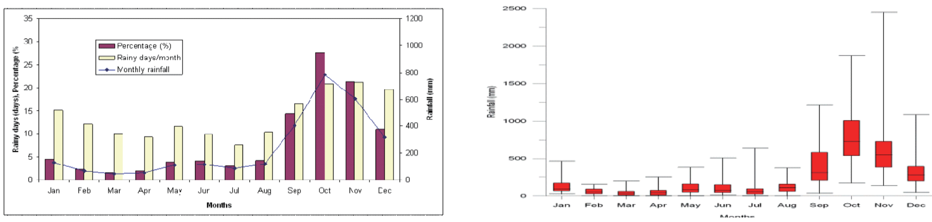
3.1. General characteristics of rainfall and rainy days

Before conducting a formal test for trends, it is necessary to perform some preliminary analysis to get an initial understanding of the data. The conclusions of this step are fundamental to choosing suitable methods for trend detection. In this paper, cross-correlation coefficients among the three stations were calculated from 0.67 (Hue and A Luoi) to 0.88 (Namdong and A Luoi) which indicates a high degree of similarity. Apparently from the box-whisker plots for three stations in Fig. 2 (right) that, the monthly rainfalls in Thua Thien Hue were either abnormally distributed or positively skewed. The graphs in Fig. 2 not only bring the spatial contrasts in Thua Thien Hue rainfall vividly to light, they also reinforce the observation that there is highly seasonal variability on the time scale. The coastal plain areas (Hue) mostly receive rainfall from September to December (four months) while the mountainous areas (Nam Dong and A Luoi) mostly receive rainfall from May until December (8 months). These findings about seasonality for each station are in agreement to the classification of dry and rainy seasons reported by NCAP (2008). In addition, noteworthy is that all three stations observed the highest rainfalls in October which contribute almost 30% of annual rainfall. The lowest rainfalls, which contribute only about 1.5% of annual rainfall, were observed in February at A Luoi and in March at Hue and Nam Dong.

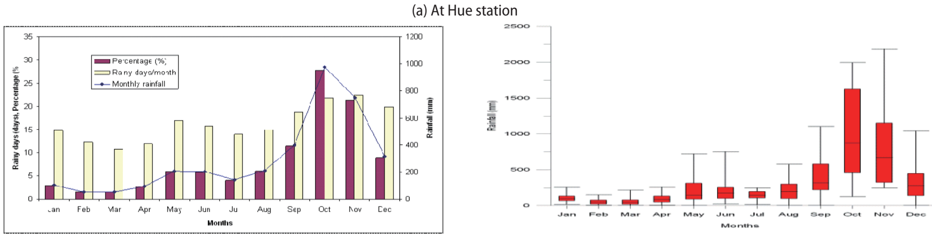
Calculation of means and coefficients of variation (CV) of 19 time series at all three stations for the common period (1976-2003), and at Hue station for the complete period (1960-2003) indicated that the mean annual rainfall greatly varies from 2832 mm at Hue station to 3513 mm at Nam Dong. Both annual rainfalls and annual rainy days in the mountainous area (Nam Dong and A Luoi stations) are much higher than those in the coastal plain (Hue station). Rainfalls in dry season at all three stations contribute only about 20% of annual rainfall, the rest are rainfalls in rainy season. While the annual and seasonal CVs are low (at about 19 to 35 percent) and slightly differ from station to station, the values for the individual months of the stations are far more extreme. Generally, the dry season months experience higher CVs than others and time series at Hue station have higher CVs than those at Nam Dong and A Luoi stations.

3.2. Trends in rainfall and rainy days

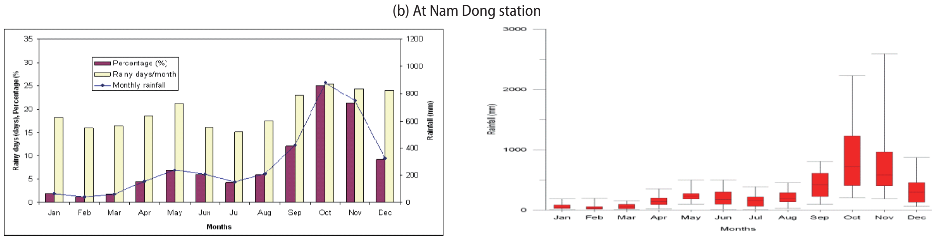
The trends results for 18 rainfall variables and annual rainy days using significance levels (α) of 5% and 1% were presented in Table 1. Trend results were classified into five groups: strong downward trend, weak downward trend, no significant trend, weak upward trend, and strong upward trend. In table 1, these groups were marked as (✕✕), (✕), (◇), (✔), and (✔✔), respectively. Apparently from Table 2 that A Luoi among stations and December rainfall among rainfall variables showed the most significant trends. All statistically significant trends found in the area are upward trends except for a weak downward trend in January rainfall at Hue for the period 1960-2003. The annual rainfall at A Luoi showed a weak upward trend over the years while annual rainfall at both Hue and Nam Dong observed no significant trend.



(a) At Hue station



(b) At Nam Dong station



(c) At A Luoi station

Fig.2 Monthly rainfall, its percentage of annual rainfall, monthly rainy days, and box-plot of monthly rainfall distribution at (a) Hue; (b) Nam Dong; and (c) A Luoi stations.

Results of trend analyses on seasonal rainfall data show no statistically significant trend at any of the stations and for any of the period of record considered. Interestingly, in spite of similarities in geographical conditions between A Luoi and Nam Dong, number of statistically significant trends observed in time series at A Luoi is much more than those in time series at Nam Dong. Additionally, annual rainy days were found to be increasing at Nam Dong, but not at A Luoi. Importantly, the investigation for the two periods at Hue leads to different trend results in January, December, and annual monthly min rainfalls.

Tables 1 also presents trend slope results for the 18 rainfall variables and rainy days that were identified as being field significant at each time series. As shown in Table 1, A Luoi showed an increasing annual rainfall at the rate of 412.7 mm/decade which is equivalent to 11.8% of the annual mean/decade. Table 1 also reveals that the upward trend slopes in December rainfalls are very different from station to station. The highest slope in December rainfall was found at A Luoi for the period of 1976-2003 (144.3 mm/decade, or 45.0% of the December mean/decade) and the lowest one at Hue for the period of 1960-2003 (40.7 mm/decade, or 13.0% of the December mean/decade). Also noteworthy is that when analyzing rainfall data at Hue station the two periods, the slopes of increasing trends in February and monthly minimum rainfalls were estimated at the rates of 44.6% of the mean/decade and 34.2% of the mean/decade, respectively, for the common period 1976–2003, even though no significant trend in these rainfall time series was found for the complete period 1976-2003. Analysis of rainy days indicates that annual rainy days increased 10 days per decade, which is about 5.1% of the mean/decade, at Nam Dong.

For presentation purpose, six examples of rainfalls and rainy days, which showed statistically significant trends, with their fitting linear trends are shown in Fig. 3. Three panels presented in Fig. 3 are corresponding to Hue, Nam Dong, and A Luoi stations, respectively.

Analyses of rainfall trends in this paper revealed several interesting features of rainfall regime in Thua Thien Hue. When using graphs to explore, Tran (2010) briefly noted trends in seasonal rainfalls at Hue. In more details, however, the current study has clarified that those trends were not statistically significant. The findings for different periods herein stress that when long records are available, rainfall periodicities (inter-decadal variation) should be taken into consideration.

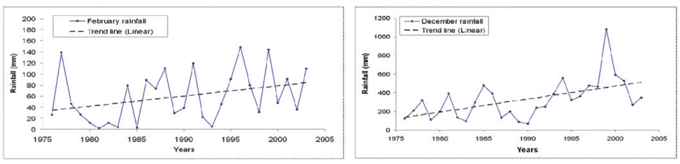
In fact, slight climatic changes may affect the rainfall regime in a given area. In spite of the uncertainties about the precise magnitude of future climate change and its possible impacts, measured trends detected herein must be taken to anticipate, prevent or minimize the causes of climate change and mitigate its adverse affects on water resources in the area. The similarities in trends and patterns in different hydroclimatic variables and close inter-correlations among them were well-documented in literature (Sharma et al., 2000; Aziz and Burn, 2006; Abu-Taleb et al., 2007). Therefore, future works will address the issue of rainfall periodicities and trends in other hydroclimatic variables (e.g. temperature, evaporation, and so on), and will attempt to clarify trend attributions and to establish a linkage between climatic change and hydrologic trends.

4. Conclusion

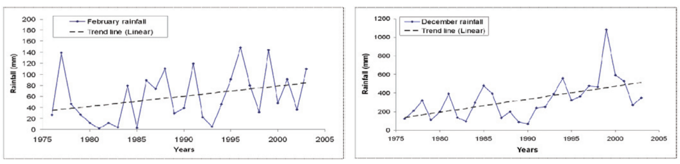
Long-term trends in rainfall and rainy days were examined for the period 1976- 2003 at all three meteorological stations (Hue, Nam Dong, A Luoi) available in Thua Thien Hue, by utilizing the non-parametric Man-Kendall trend test and Sen's slope estimator. This study revealed that A Luoi among stations and December rainfall among rainfall variables showed the most significant trends. All statistically significant trends found at 1% and 5% in the area were upward trends. No significant trend was found in annual and seasonal rainfalls except for a weak upward trend observed in annual rainfall at A Luoi station. Interestingly, the investigation for the two periods at Hue leads to different trend results in January, December, and annual monthly min rainfalls. The trend slope estimation indicated that A Luoi showed an increasing annual rainfall at the rate of 412.7 mm/decade (11.8% of the mean/decade). In December rainfalls, the highest trend slope was found at A Luoi (144.3 mm/decade, or 45.0% of mean/decade) and the lowest one at Hue (40.7 mm/decade, or 13.0% of mean/decade). Annual rainy days increased 10 days per decade at Nam Dong. Since

Table 2: Trends and their slopes (amount of change per decade (% of mean/decade)) in rainfall and rainy days in Thua Thien Hue

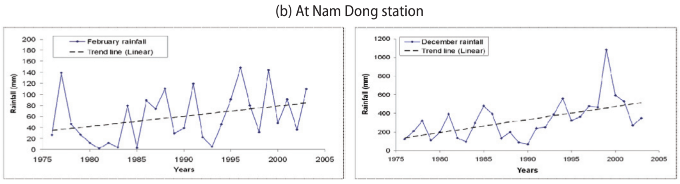
No	Rainfall variables	Hue station		Nam Dongstation	A Luoi station
		(1960-2003)	(1976-2003)	(1976-2003)	(1976-2003)
1	January rainfall	✕ 16.7 (13.2%)	◇	◇	◇
2	February rainfall	◇	✔ 27.4 (44.6%)	◇	✔✔ 19.1 (36.4%)
3	March rainfall	◇	◇	◇	◇
4	April rainfall	◇	◇	◇	◇
5	May rainfall	◇	◇	◇	✔ 31.9 (13.3%)
6	June rainfall	◇	◇	◇	◇
7	July rainfall	◇	◇	◇	◇
8	August rainfall	◇	◇	◇	✔ 53.5 (25.5%)
9	September rainfall	◇	◇	◇	◇
10	October rainfall	◇	◇	◇	◇
11	November rainfall	◇	◇	◇	◇
12	December rainfall	✔ 40.7 (13%)	✔ 142.4 (40%)	✔✔ 121.3 (38.3%)	✔✔ 144.3 (45.0%)
13	Annual rainfall	◇	◇	◇	✔ 412.7 (11.8%)
14	Dry season rainfall	◇	◇	◇	◇
15	Rainy season rainfall	◇	◇	◇	◇
16	Daily max rainfall	◇	◇	◇	◇
17	Monthly Max rainfall	◇	◇	◇	◇
18	Monthly Min rainfall	◇	✔ 4 (34.2%)	◇	✔ 6.7 (27.0%)
Rainy days					
19	Annual rainy days	◇	◇	✔ 10.0 (5.1%)	◇



(a) At Hue station



(b) At Nam Dong station



(c) At A Luoi station

Figure 3: Examples of rainfalls and rainy days and their trend lines at (a) Hue; (b) Nam Dong; and (c) A Luoi stations.

rainfall is a good indication of climate change impacts on water resources, measured trends detected herein must be taken to anticipate, prevent or minimize the causes of climate change and mitigate its adverse affects on water resources. The findings from this study provide useful references for sustainable water resources development in Thua Thien Hue.

5. Acknowledgments

The authors are grateful to the Hydro-meteorological Data Center of Vietnam for providing hydroclimatic data, and to the Global Center of Excellence for Sustainable Urban Regeneration, University of Tokyo, for the financial supports. The authors also acknowledge colleagues' suggestions, which have contributed to marked improvements in the content of our paper.

6. References

Abu-Taleb, A.A., Alawneh, A. J., Smadi. M.M., (2007). Statistical Analysis of Recent Changes in Relative Humidity in Jordan. *American Journal of Environmental Sciences*. 3 (2), 75-77.

Aziz, O.I.A., Burn, D.H., (2006). Trends and variability in the hydrological regime of the Mackenzie River Basin. *Journal of Hydrology*. 319, 282–294.

Basistha, A., Goel, N.K., Arya, D.S., Gangwar, S.K., (2007). Spatial patterns of trends in long Indian sub-divisional rainfall. *Jalvigyan Sameeksha (Hydrology Review)*. 22, 47-57.

Boyles R.P., Raman S., (2003). Analysis of climate trends in North Carolina (1949–1998). Environment International. 29, 263–275.

Burn, D.H., Elnur, M.A. H., (2002). Detection of hydrologic trends and variability. *Journal of Hydrology*. 255 (1-4), 107-122.

Endo, N., Matsumoto, J., Lwin, T., (2009). Trends in Precipitation Extremes over Southeast Asia. SOLA. 5, 168-171.

Esterby, S. R., (1998). Review of methods for the detection and estimation of trends with emphasis on water quality applications. *Hydrological processes*. 10 (2), 127 – 149.

Kahya, E., Partal, T., (2007). Is seasonal precipitation decreasing or increasing in Turkey? *Online Journal of Earth Sciences*. 1, 43-46.

Kumar, V., Jain, S.K., (2010). Trends in seasonal and annual rainfall and rainy days in Kashmir Valley in the last century. *Quaternary International*. 212(1), 64-69.

Kundzewicz, Z. W., Robson, A.J., (2004). Change detection in hydrological records— a review of the methodology. *Hydrological Sciences–Journal–des Sciences Hydrologiques*. 49(1), 7-19.

Manton, M.J., Della-Marta, P.M., Haylock, M.R., Hennessy, K.J., Nicholls, N., et al., (2001). Trend in extreme daily rainfall and temperature in south Asia and south pacific: 1961-1989. *International Journal of Climatology*. 21(3), 269-284.

Mosmann, V., Castro, A., Fraile, R., Dessens, J., Sanchez. J.L., (2004). Detection of statistically significant trends in the summer precipitation of mainland Spain. *Atmospheric Research*. 70, 43–53.

NCAP. (2008). Climate Change Impacts in Huong River Basin and Adaptation in its coastal district Phu Vang, Thua Thien Hue province. *Project report*. pp. 142.

Serrano, A., Mateos, V. Garcia, J. (1999). Trend analysis of monthly precipitation over the Iberian Peninsula for the Period 1921-1995. *Phys. Chem. Earth* (B), 24(l-2), 85-90.

Sharma, K., Mooreiii, B., Vorosmarty, C., (2000). Anthropogenic, Climatic, and hydrologic trends in the Kosi basin, Himalaya. *Climatic Change*. 47 (1-2): 141-165.

Tran, V.G.P., (2010). Flood risk management in the the Huong River Basin. *Proceedings of International workshop on Waterlong Community-Hue*. Tokyo, 11, January. CD Rom.