Overall and Partial Trend Identification of High Resolution Gridded Rainfall Data over Vietnam by Applying Innovative-Şen Trend Analysis (ITA) Method

T H Phan¹, N D P Dang¹, M H Le², T H Nguyen³, N T Nguyen³, N P Hoa⁵ and K L Nguyen¹*

¹Research Center for Climate Change (RCCC) - Nong Lam University Ho Chi Minh City, Vietnam; ²Department of Science and Technology, Gia Lai Province, Vietnam ³Faculty of Environment and Natural Resources - Nong Lam University Ho Chi Minh City, Vietnam; ⁴Faculty of Economics - Nong Lam University Ho Chi Minh City, Vietnam; ⁵Faculty of Fisheries - Nong Lam University Ho Chi Minh City, Vietnam;

*Correspondence: ngkloi@hcmuaf.edu.vn; Tel.: +84 989 617 328

Abstract. Trend detection in rainfall time series is a prime task to provide reliable outcomes for better planning and management of water resources under climate change. This study investigated the rainfall trends in seasonal and monthly rainfall over Vietnam, using high-resolution gridded datasets from 1980 to 2010. Possible trends in rainfall values were detected by a recently proposed Innovative-Şen Analysis (ITA) method, which allows identifying the trends of the low, medium, and high values of a series. The outcomes showed high domination of significantly increasing trends in annual rainfall. Moreover, the analysis of partial trends in the time series identified a sequence of alternating decreasing, increasing, and trendless seasonal and monthly rainfall. On the other hand, opposite trends were found for extreme rainfall, in which the high values in the rainy season showed negative trends, while the positive trends of low values in the dry season were indicated. Besides, based on categorization, the low, medium, and high monthly rainfall values of the seven sub-regions were mainly evaluated, which occurred in different trends. The high values in monthly of the rainy season had also detected an upward trend, and the low values in monthly dry season existed downward trends that are expected that these results will be associate with rainfall trends with floods and droughts. Besides, the study showed that the ITA method could be successfully used in trends analysis for gridded datasets of rainfall variables.
1. Introduction

Amongst the implications of climate change, the intensification of precipitation extremes is one of the most important aspects [1]. The potential changes in precipitation extremes are of significant importance, as precipitation extremes have a broad range of concerns to natural and human systems, such as increasing flood and drought risks [2]. Increases in extreme events (i.e., urban floods and water stress) have drawn great attention on climate change and has attracted increasing attention of hydrologist and climatologist. Therefore, understanding and identifying changes in frequency and magnitude of precipitation extremes are vital to develop mitigation strategies ranging from management policies to infrastructure adaption.

On the one hand, from historical literature reviews, the changes in rainfall extremes at the regional scale are not completely compatible with that observed at the global scale, due to the influence of other factors that may impose a significant effect on regional rainfall patterns (i.e., land-use change, increasing aerosol due to air pollution). As a result, rainfall extremes can be characterized by a downward trend, or a mix of both upward and downward trends at the regional scale. For instance, the western and central areas of Spain was associated with a trend toward increasing changes in precipitation extremes, while the decreasing was more apparent over the eastern side [3]; and precipitation extremes generally exhibit decreasing trends in the southeastern such as Anatolia and Mediterranean regions, whereas northwestern Turkey was characterized by increasing trends [4. Regional and national assessments, therefore, are important to provide a holistic understanding of changes in precipitation extremes in response to a warming climate, especially for regions of which precipitation extremes have a significant impact on natural and human systems. On the other hand, several countries, including Vietnam, still have a relatively sparse network with manual collecting procedures [5]. Therefore, a vary high-resolution gridded rainfall datasets has been interpolated from rainfall data sources at station and popularly applied over the world, such as the monthly Climate Research Unit (CRU) data [6], the Global Precipitation Climatology Project (GPCP), the Global Precipitation Climatology Centre (GPCC) [7], the 6-hourly National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) Corrected by CRU (NCC) [8], the monthly and pentad Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP) [9], the daily Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation (APHRODITE) [10] datasets. Each dataset has merits and demerits and was built based on different techniques and different input data sources.

In general, parametric and non-parametric statistical analysis methods have been approached for meteorological, hydrological and climatological variables by many researcher and organization over the world. The studies have evaluated for each method and compared the approaches together. As the results, without restrictive assumptions such as distribution hypothesis, series correlation, seasonal period and time series size, Innovative- Şen trend analysis has universal applicability. In addition, Şen (2012) proposed the Innovative Trend Analysis (ITA) technique which allows identifying not only monotonically over a given time period but also whether the low, medium and high values have separate trends [11]. For instance, Caloiero (2017) analyzed the seasonal and monthly rainfall trends by means of a new graphical technique. This report confirmed that the ITA method could be successfully used to evaluate the high and low data values for rainfall trends analysis in Italy [12]. Cui (2017) inspected data of rainfall and temperature variables for the time period 1960 and 2015 years by using Mann-Kendall test, Şen slope and Innovative-Şen Trend Analysis method in China. They determined that some no clear trends observed by Mann-Kendall test could be described by the ITA method [13]. Wang (2020) employed ITA method to demonstrate the trends of rainfall over 55-years
period in the Yangtze River Delta, eastern China. The results detected that the increasing trends in annual rainfall, summer and winter at all station, while the decreasing trends in spring and autumn. In addition, this study showed a close relationship between rainfall trends and extreme events [14].

Under the effect of monsoon and complex topography, Vietnam is prone to natural disasters such as storm, floods and drought [15]. In the past recent years, the detection of trend component in the hydro–meteorological has also attracted increasing attention of the Vietnamese hydrologists and climatologist. Although the researchers have been paid to the studies of rainfall changes over Vietnam, limited number of studies have focused on temporal variations in different categories. Besides, the low and high values of rainfall are confirmed the important signals focus occurrence of the floods or droughts. Moreover, almost all the researcher have just been explored by the classical methods such as linear regression (LR) [16][17], and Mann-Kendall (MK) method [5][18][19][20]. Therefore, the objectives of this study are to (1) investigate the trends of long-term rainfall data over Vietnam; (2) detect the trends of seasonal and monthly rainfall series in different rainfall categories (low, medium, and high) for high-quality gridded precipitation observation data from 1980 to 2010 by mean ITA method.

2. Study area and data

Within this study, the area under investigation was seven climate sub-regions in Vietnam, which located in the centre of two main tropical monsoon areas, the South Asian and the East Asian monsoons, and lying approximately from 8°N to 23°N in latitude and 102°N to 109°N longitude as shown in Figure 1. Therefore, Vietnam has a tropical monsoon climate with a seasonal reversal in atmospheric circulation and precipitation associated with the thermal contrast in east-west or land-sea heating [21]. Besides, the total area of Vietnam is approximate 332,000 km², with significant coastline length approximately 3,260 km and more than 70% of the people depend on agriculture for their livelihood [19]. Based on the different in radiation, temperature, and rainfall condition, Vietnam was classified into seven climate sub-regions, consisting of the Northwest, Northeast, Northern Delta, North Central Coast, South Central Coast, Central Highlands, and Southern regions [22]. Over the sub-regions the rainy season accounts for approximately 75-85% of the annual rainfall. The average annual rainfall over the country is approximately 1,400 - 2,400 mm can vary from 700 mm up to 5,000 mm, depending on each region [19]. In recent years, extreme events are frequent and it has a wide range of impact on agricultural and water resources sector. Therefore, characteristic information about hydro-meteorological trends is becoming extremely necessary to the decision policy makers [13].
Figure 1. Spatial distribution of seven climate regions in Vietnam.

The high-resolution Vietnam gridded Precipitation data for the period 1980 - 2010 were primarily used for a rainfall analysis. These data were constructed at 0.1°x 0.1° and 0.5°x0.5° latitude-longitude resolution using observations at 481 rainfall stations across Vietnam by Nguyen Xuan Thanh. An overview of these selected gridded datasets is provided in Table 1. The most recent Vietnam-gridded precipitation data (VnGP) were constructed using 481 rain gauges over Vietnam [23]. It was noted that among multiple interpolations tested, the Spheremap interpolation technique showed relatively better performance compared to the other methods such as the Inversed Distance Weighting (IDW), Kringing and Cressman methods and was therefore chosen to construct the VnGP. These data sets are available at daily time scale in two different spatial resolutions (0.5°x0.5° and 0.1°x0.1°) for the time period 1980-2010. The VnGP has validated as the best precipitation observation gridded data that is currently a good representation of gauge observations over Vietnam. Therefore, in this study utilize VnGP as the reference for the gridded observation datasets.

3. Methodology

A workflow analysis steps were epitomized in Figure 2. First, the daily gridded rainfall dataset of high resolution gridded in Vietnam was collected, processed, and preliminary assessed the change of
temporal and spatial rainfall data through technical and map analysis. Then, the overall and sub-trends of monthly and seasonal rainfall trends over Vietnam were determined by using ITA method.

Innovative – Şen Trend analysis method

The Innovative Trend analysis (ITA) method has been proposed by Şen in 2012, which has been used to analysis trends in the long rainfall time series. The fundamental basis of the ITA method is constructing a scatter plot of a set of subseries derived from a given time on a Cartesian coordinate system [24][25][26][27]. This method is not only analyzes the overall trend for the entire period but can also identify partial trends based on the classification of groups. The low, medium and high-value groups of hydro-meteorological data are arranged according to expert view or the variation over time in the first half-time X-axis are considered based on the mean X; and the standard deviation, SX, which helps to determine the ranges of low, medium, and high values as $X < \bar{X} - S_x$, $\bar{X} - S_x < X < \bar{X} + S_x$, $X > \bar{X} - S_x$, respectively [28].

Zekâi Şen (2012, 2017) has clearly described the approach about the process and implement this method in his research. First, the time series was divided into halves, which were separately sorted in ascending order, respectively. A hydrological time series was divided into two equal halves from the first date to the end date (Xi: $i = 1, 2, ..., n/2$ and Xj: $j = n / (2 + 1), n / (2 + 2), ..., n$). Then, both sub-series are separately sorted by ascending by the magnitude of value. The first sub-series (Xi) is presented on the X-axis, and the other sub-series (Xj) is presented on the Y-axis based on the Cartesian coordinate system. The length of both the axis had to be equal and the 1:1 line divides the
diagram into two equal triangles. If the points in scatter plot fall into 1:1 (45°) line or close to this line within a 10% error range, this indicates no significant trend in the time series. If the points in scatter plot are located upper and lower the line with slope 1:1 (45°) line, this indicates the non-monotonic trends (may be increase or degree) in the time series. Besides, if the values scatter above and below the 1:1 line, data will be categorized as the value series into each value group.

4. Results and discussion

4.1. Trends in annual rainfall at seven climate sub-regions

Figure 3 summarizes the results of annual rainfall trends for seven climate sub-regions over the period 1980 – 2010. The results of trend detections obtained by ITA method as shown in Figure 4. In these figure, the red diamond points are centroid values used for indicating overall trends and the grey circle, square, and triangle points illustrate mean central points of low, medium, and high rainfall, respectively. Results of the overall and partial annual rainfall trend analysis detected by the ITA method were summarized in Figure 3 with both negative and positive trends for all variables. The monotonic trends in annual rainfall from 1980 to 2010 detected by ITA method were represented through diamond red points illustrated mean central points. With regards to different rainfall cluster circle, square and triangle points shape illustrated of low, medium and high values, respectively. As concerns the mean values in annual rainfall, four regions were analyzed including Northwest, Northeast, North Delta, and North Central Coast represent the North in Vietnam were detected non-trend among regions in the period from 1980 to 2010. Three regions in the South including South Central Coast, Central Highlands and Southern shown an increasing trends for mean annual rainfall values.

In addition, the method used to investigate partial trends identifies of significant change in the rainfall series. In sub-trend of rainfall clusters, high rainfall values had strongest increasing trend at Northwest but clearly decreasing trends in Northern Delta. For instance, In the South of Vietnam, the ITA results
show that most points fall above the 1:1 line implying an overall upward trend for the South. However, the features of trends in different rainfall categories were quite distinct at each region. At the Central Highlands and Southern Delta, low rainfall had no trend, while medium and high rainfall had a strong increasing trend, especially the high rainfall values. Applying ITA method for categories values in North, as revealed by Figure 3, the patterns of rainfall variation over time also had not been the same for all the data sets investigated. While all of the values (low, medium, high) and overall trend in the sub climate regions identified no trend, the Northwest and Northern Delta shown increasing and decreasing, respectively.

4.2. Seasonal trends

The rainfall trends over the two seasons including mean, minimum and maximum values, which detected by the ITA methods are summarized from Figure 4 to Figure 7. On the one hand, graphical results shown overall trends, which also were illustrated by red diamond points. On the other hand, the method used to investigate partial trends identifies times of significant change in the rainfall series. The scatter points in the graphic shown both upward and downward values existed in almost regions. Meanwhile, applying 10% line band, the trends were identified clearly and specifically with the trends were upward in medium and high values of the categories. For instance, in the Northwest (Figure 4) where the scatter point fell in below and above of 1:1 line, however, the result evaluated a light decreasing trends by using ITA method.

As regards the mean rainfall values in dry and rainy season, the result of the ITA procedure for the seven climate sub-regions were represented in Figure 4 and Figure 5. In this case, the variation overall trends of mean rainfall values both two seasons were nearest that of annual rainfall, which had no trend in the Northern plain, when a decreasing trends in the Southern areas were observed. As concerns the mean rainfall in dry season (Figure 4), no clear trend were evident for all regions except North Central Coast showed the increasing for overall and partial trends. One highlight shown that while the average annual rainfall value (Figure 3) and the maximum in the rainy season of the North Central Coast region (Figure 5) did not show the trend, the trend of average rainfall in the dry season (Figure 4) increased for both the overall trend and for all rainfall value groups (low, medium and high), indicating that may be associate with extreme rainfall extremes in this region.
Figure 4 Innovative Şen trend plots for mean rainfall values in dry season in seven climate sub-regions in Vietnam

Figure 5 Innovative Şen trend plots for mean rainfall values in rainy season in seven climate sub-regions in Vietnam

Significant trends were also detected at seven climate sub-regions in minimum values in dry season and maximum values in rainy season were significantly illustrated through the Figure 6 and Figure 7.
Graphically evaluated the quantitative variables with ranges of minimum values in dry season from 20 to 80 mm per year, while in rainy season with highest values revealed to 1,800 mm per year. So, the method had not only depicted trends in overall and partial trends, but shown quantitative values for rainfall series in Vietnam. With low variables in minimum values dry season-based on for the tropical climates, a dry season month is defined as a month when average precipitation is below 60 mm and high variables, the change of rainfall is easy to cause the extreme rainfall phenomena. Therefore, indicating the trends in minimum rainfall in dry season and maximum values in rainy rainfall had assessed vital issue for Vietnam. In addition, when partial trends were evaluated minimum variable, in Northeast and North Central Coast appeared increasing trends for overall and sub-period (medium and high variables). In Figure 6, minimum rainfall in dry season, Northeast and North Central Coast had decreasing change in overall minimum rainfall values in dry season between 1980 and 2010, described a significant trends difference in the Northeast and North Central Coast with another regions. In detail, the results shown an uptrend for all different categories (low, medium, and high) in the Northwest and the medium and high-values in the North Central Coast. In the South climatic regions, trends analysis were obtained through maximum values in the rainy season. The ITA method used to provide evidence of trends differences between sub-categories (low, medium and high values) for each region and distinguished trends between all regions. Except for the high-value group in Central Highlands which is in the uptrend and the low-value group in Southern which is in the downtrend, all other values have no trend when it is in the ±10% band line.
Figure 7 Innovative–Şen trend plots for maximum rainfall values in rainy season in seven climate sub-regions in Vietnam

Particularly for the trend of the maximum rainfall values for the rainy season, which has been determined by the ITA method, shown in detail in Figure 7. In this case, there exists a big difference from the other values of and seasonal and seasonal rainfall for the Northeast region when there is a slight decrease in the high-value group. Besides, the Southern region is the region where there is only a downward trend (for the low-value group) relative to all regions in the south and also for the North.

5. Conclusion

In this study, the trends of annual and seasonal across the seven climate sub-region in Vietnam during 1980-2010 were investigated by the Innovative-Şen Trend Analysis (ITA) technique. The results of trend detection showed high domination of increasing trends in the annual and seasonal rainfall time series, but mostly significant trends were observed in the dry season. Furthermore, the graphical method described the quantitative rainfall results on the Descartes axis, which were the evidence the rainfall in the rainy season contributes to the total annual rainfall values. However, these results are apparent that the dry season precipitation value can be considered a vital factor in determining the change in rainfall of climatic regions.

In general, this study paints an overall picture of long-term rainfall variability in terms of temporal data, which created the picture to consider and apply partial trends analysis over the past 31 years. This result is expected to be one of the premises for analyzing historical rainfall trends and motivation for research related to analyzing past trends and building trend scenarios for the future.

6. References
Papalexiou, Simon Michael, and Alberto Montanari. 2019. “Global and Regional Increase of Precipitation Extremes Under Global Warming.” *Water Resources Research* **55**(6):4901–14. doi: 10.1029/2018WR024067.

IPCC 2014. *Future Climate Changes, Risks and Impacts. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*

Río S, Herrero L, Fraile R, and Penas A 2011. “Spatial Distribution of Recent Rainfall Trends in Spain (1961-2006).” *International Journal of Climatology* **31**(5):656–67. doi: 10.1002/joc.2111.

Hadi S J, and Mustafa T 2018. “Long-Term Spatiotemporal Trend Analysis of Precipitation and Temperature over Turkey.” *Meteorological Applications* **25**(3):445–55. doi: 10.1002/met.1712.

Phan V T, and Ngo D T 2013. “Biến Đổ i Khí Hậu ở Việt Nam - Một Số Kết Quả Nghiên Cứu, Thách Thức và Cơ Hội.” **2**:42–55.

Harris I, Jones P D, Osborn T J, and Lister D H 2014. “Updated High-Resolution Grids of Monthly Climatic Observations - the CRU TS3.10 Dataset.” *International Journal of Climatology* **34**(3):623–42. doi: 10.1002/joc.3711.

Viana, Denilson R, and Sansigolo C A 2016. “Monthly and Seasonal Rainfall Forecasting in Southern Brazil Using Multiple Discriminant Analysis.” *Weather and Forecasting* **31**(6):1947–60. doi: 10.1175/WAF-D-15-0155.1.

Phan V T, Fink A H, Trinh T L, and Pinto J G 2014. “EWATEC-COAST: Technologies for Environmental and Water Protection of Coastal Zones in Vietnam Contributions to 4 Th International Conference for Environment and Natural Resources — ICENR 2014.” 4th International Conference for Environment and Natural Resources, ICENR (June).

Arkin X 1997. “Global Precipitation: A 17-Year Monthly Analysis Based on Gauge Observations, Satellite Estimates, and Numerical Model Outputs, Bulletin of the American Meteorological Society, **78**, 2539-2558.”

Kamiguchi K, Osamu A, Akio K, Akiyo Y, Atsushi H, and Natsuko Y 2010. “Development of APHIRO_JP, the First Japanese High-Resolution Daily Precipitation Product for More than 100 Years.” *Hydrological Research Letters* **4**(6):60–64. doi: 10.3178/hrl.4.60.

Şen Z 2012. “Innovative Trend Analysis Methodology.” (September):1042–46. doi: 10.1061/(ASCE)HE.1943-5584.0000556.

Caloiero T, Coscarelli R, and Ferrari E 2017. “Analysis of Rainfall Trend in Southern Italy through the Application of the ITA Technique.” *European Water* **59**(2014):199–206.

Cui L, Wang L, Zhongping L, Qing T, Wen L, and Jun L 2017. “Journal of Atmospheric and Solar-Terrestrial Physics Innovative Trend Analysis of Annual and Seasonal Air Temperature and Rainfall in the Yangtze River Basin, China during 1960 – 2015.” *Journal of Atmospheric and Solar-Terrestrial Physics* **164**(June):48–59. doi: 10.1016/j.jastp.2017.08.001.

Wang, Yuefeng, Youpeng X, Hossein T, Wang J, Wang Q, Song S, and Zunle H 2020. “Innovative Trend Analysis of Annual and Seasonal Rainfall in the Yangtze River Delta, Eastern China.” *Atmospheric Research* **231**(37):104673.
Endo N, Matsumoto J, and Tun L 2009. “Trends in Precipitation Extremes over Southeast Asia.” Scientific Online Letters on the Atmosphere 5(1):168–71. doi: 10.2151/sola.2009-043.

Caesar J L V, Alexander B, Trewin K, Tse-ring L, Sorany V, Vuniyayawa N, Keosavang A, Shimana M M, Htay J, Karmacharya D A, Sakkamart J J, Soares E, Luong T H, Le T T, Chu T H, Nguyen T T D, Pham V H, Hoang D C, Nguyen M C, and Sirabaha S 2011. “Changes in Temperature and Precipitation Extremes over the Indo-Pacific Region from 1971 to 2005.” International Journal of Climatology 31(6):791–801. doi: 10.1002/joc.2118.

Chu T H, Vu T H, Pham T L H, and Phan V T 2010. “Mức Độ và Xu Thế Biến Đổi Của Nắng Nóng ở Việt Nam Giai Đoạn 1961-2007 - Variations and trends in hot events in Vietnam from 1961 to 2007”. Tạp chí Khoa học ĐHQGHN, Khoa học Tự nhiên và Công nghệ 26, 370-383

Dao N K, and Hoang T T 2016. “Analysis of Changes in Precipitation and Extremes Events in Ho Chi Minh City, Vietnam.” Procedia Engineering 142:229–35. doi: 10.1016/j.proeng.2016.02.036.

Nguyen D K, Tiho A, and Alan R 2019. “Evidence of Climatic Change in Vietnam: Some Implications for Agricultural Production.” Journal of Environmental Management 231(October 2018):524–45. doi: 10.1016/j.jenvman.2018.10.011.

Nguyen D Q, James R, and James M 2014. “Variations of Surface Temperature and Rainfall in Vietnam from 1971 to 2010.” International Journal of Climatology 34(1):249–64. doi: 10.1002/joc.3684.

Nicholls, Robert J, Natasha M, Jason A L, Brown S, Pier V, Gusmão D D, Jochen H, and Richard S J T 2011. “Sea-Level Rise and Its Possible Impacts given a ‘beyond 4°C World’ in the Twenty-First Century.” Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 369(1934):161–81. doi: 10.1098/rsta.2010.0291.

Nguyen D N 2013. Tài Nguyên Khí Hậu Việt Nam . NXB Khoa Học và Kỹ Thuật.

Nguyen X T et al 2016. “The Vietnam Gridded Precipitation (VnGP) Dataset : Construction and Validation.” 12:291–96. doi: 10.2151/sola.2016-057.

Abdullah, M M, Şen Z, Almazroui M 2017. “Trend Analyses Revision and Global Monthly Temperature Innovative Multi-Duration Analysis.” 1–13. doi: 10.1007/s41748-017-0014-x.

Şen Z 2015. “Innovative Trend Significance Test and Applications.” doi: 10.1007/s00704-015-1681-x.

Öztopal, Ahmet, and Şen Z 2016. “Innovative Trend Methodology Applications to Precipitation Records in Turkey.” doi: 10.1007/s11269-016-1343-5.

Wu, Hao, and Hui Q 2016. “Innovative Trend Analysis of Annual and Seasonal Rainfall and Extreme Values in Shaanxi, China, since the 1950s.” International Journal of Climatology 37(5):2582–92. doi: 10.1002/joc.4866.

Alashan S 2018. “An Improved Version of Innovative Trend Analyses.” Arabian Journal of Geosciences 11(3). doi: 10.1007/s12517-018-3393-x.