



# Application of the ITA approach to analyze spatio-temporal trends in monthly maximum rainfall categories in the Vu Gia-Thu Bon, Vietnam

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## Abstract

This study aims to investigate the trend behavior of monthly maximum in daily rainfall categories in the Vu Gia-Thu Bon river basin located in central Vietnam. Daily maximum rainfall series from 12 rainfall stations for the period 1979–2018 were utilized to characterize six categories of the intensity of daily maximum rainfall: light (0–4 mm/day, category A), mild-moderate (4–16 mm/day, category B), moderate-heavy (16–32 mm/day, category C<sub>1</sub>), heavy (32–64 mm/day, category C<sub>2</sub>), heavy-torrential (64–128 mm/day, category D<sub>1</sub>), and torrential ( $\geq 128$  mm/day, category D<sub>2</sub>). The new approach of the Innovative Trends Analysis was then applied to the six classified categories. The results revealed that category B had a dominant increasing trend (32% of rain events) for all the stations in January (5.85%) and February (3.44%). In March and April, category A was dominant with 45% and 20%, respectively. In July, category C<sub>1</sub> was dominant with 25%, while in August and September, category C<sub>2</sub> prevailed over all stations with 45% (all stations) and 20%, respectively. The categories D<sub>1</sub> and D<sub>2</sub> were observed at all stations in December and November, with 26% and 31% of events, respectively. These results indicate an increasing trend in the categories B, C<sub>1</sub>, C<sub>2</sub>, and D<sub>1</sub>.

**Keywords** Modified ITA · Monthly extreme rainfall · Rain category · VGTB · Vietnam

## 1 Introduction

Localized flooding related to intense and short-term rainfall is a frequent hazard around the world whose probability may increase due to global warming. Climate change has already affected the intensity of precipitation, hence

the need to study possible changes in the probability of daily precipitation intensities across the world (McBride et al. 2022). Short lasting intense precipitation events pose a serious threat to society and the environment triggering extreme climatic hazards, such as landslides and fast floods (Forecasting extreme precipitation in the central Mediterranean: changes in predictors' strength with prediction lead time. 2022; Wu et al. 2021). The latter, generated directly by torrential daily rainfall, can cause devastating human and economic damage (Giuseppe et al. 2020; Hegerl et al. 2014). Given the potential risks of extreme precipitation events, it is crucial to study and monitor their intensity, particularly in regions strongly affected by current climate change.

According to the Climate Risk Index, Vietnam ranks as the sixth most affected country by extreme weather events over the past two decades (Dong et al. 2022a; Eckstein et al. 2019). The Fifth Assessment Report (AR5) of the IPCC indicates that there is a high likelihood of future increases in extreme rainfall associated with monsoons in regions such as South America, Africa, East Asia, South

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Asia, and Southeast Asia (IPCC, Intergovernmental Panel on Climate Change (IPCC 2013)). Due to its geographical location in the Southeast Asian typhoon belt, Vietnam experiences a high frequency of torrential rains and storms (Thi et al. 2019).

Floods are one of the most catastrophic climatic hazards that have a major impact on the economy, environment, and society in many parts of the world. Every year, approximately 250 million people are affected by floods, resulting in more than \$40 billion in losses worldwide (A satellite-based Standardized Antecedent Precipitation Index (SAPI) for mapping extreme rainfall risk in Myanmar remote sensing applications 2022; Hallegatte et al. 2013). To mitigate the significant consequences of this natural disaster, it is crucial to develop robust approaches and appropriate tools for quantifying, and assessing the risks of extreme rainfall and flooding.

Trend analysis is a very effective tool for examining the impacts of climate change and comprehending past variations in extreme rainfall events, which is a critical step in managing climate-related hazards in a rapidly warming world (Javier et al. 2022; Dong et al. 2022b; Benzater et al. 2021b). In northeast Vietnam, the annual average temperature has increased by 0.72 °C over the past two decades compared to the period 1962–1990 (Thi et al. 2019). The Clausius-Clapeyron (CC) equation shows that a warmer atmosphere can result in a higher moisture holding capacity; and hence, there is the possibility of an increase in extreme rainfall. In addition, climate projections indicate an increase in extreme precipitation in regions where the total precipitation is expected to decrease (Dong et al. 2022c).

Our study focuses on the Vu Gia-Thu Bon (VGTB) river basin in central Vietnam, which lies in a tropical monsoon climate zone with influence from the eastern ocean. The mountainous regions of the basin receive high levels of rainfall, with an average of 3000–4000 mm annually, compared to 2000 mm in the coastal areas. During the period from September to December, the coastal regions receive the highest concentration of rainfall, ranging from 60 to 76% of annual total which can be related to the occurrence of storms and typhoons that cause flooding in the area. By studying the VGTB basin, we aim to gain a better understanding of changes in the intensity of daily precipitation in this region which is useful for developing effective strategies to mitigate the risks associated with flooding.

To better understand the impact of these conditions, both local and international studies have been conducted on severe flooding in the VGTB river system and central Vietnam. For example, Khoi et al. (Nguyen and Trang 2016) and Vo et al. (Vo et al. 2016) have conducted research on the topic.

The aim of this study is to analyze spatio-temporal trends in the monthly maximum of daily precipitation intensities in the Vu Gia-Thu Bon (VGTB) river basin in central Vietnam during the period 1979–2018, using the modified ITA method by Benzater et al. (2021a). The results obtained from this study can offer valuable insights for adaptation to the risks of disasters related to extreme precipitation in the context of climate change.

## 2 Study area and data

### 2.1 Study domain

The Vu Gia-Thu Bon River Basin (VGTB) is situated in the central region of Vietnam, and it is one of the country's largest river systems (Fig. 1). The basin's northern latitude falls between 15°00' and 16°00' and its eastern longitude ranges from 107°00' to 108°30' (Fig. 1a). It has an area of approximately 10,350 km<sup>2</sup> and consists of two main sub-basins, Vu Gia and Thu Bon (Fig. 1a).

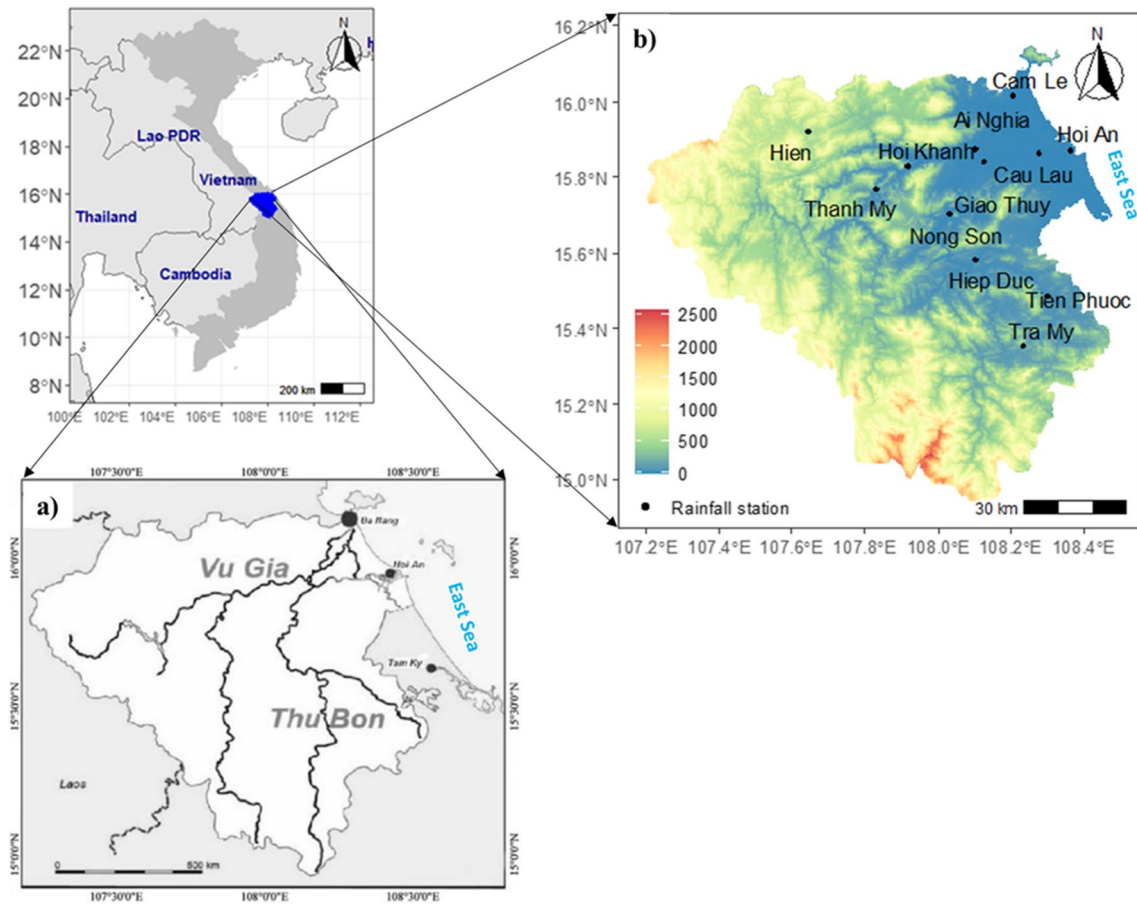
The Thu Bon Basin has an area of 3150 km<sup>2</sup> with an average annual flow twice that of the Vu Gia River basin (1850 km<sup>2</sup>). The VGTB basin is narrow mountainous, with a maximum elevation of 2600 m upstream and a flat area downstream (Fig. 1b). Therefore, the basin has steep and wide tributaries in the middle zone and a flat coastal zone, making the topography complex. The watershed region is subject to a monsoon-like climate with two distinct seasons: dry (November to April) and wet (May to October) (Souvignat et al. 2014).

The region is prone to natural hazards, including drought, floods, and typhoons, due to its heavy rainfall (Vo et al. 2016). The average annual rainfall in the region ranges from 2000 to 4000 mm. Rainfall varies depending on the basin's topography and fluctuates significantly between dry and rainy seasons. Specifically, the rainy season accounts for 57 to 74% of the annual rainfall. In contrast, the dry season contributes 26 to 43% of the annual rainfall.

The VGTB region is primarily known for its rice production, making agriculture a key focus of the local economy.

### 2.2 Meteorological and hydrological data

Observed daily rainfall data for the period 1979–2018 from 12 rainfall stations in the VGTB basin were used in this study (Fig. 1b). This dataset was obtained from the Institute of Meteorology, Hydrology and Environment (IMHEN), Ministry of Natural Resources and Environment (MONRE), Vietnam. The network of 12 rainfall stations in the VGTB basin is sparse, with only one station



**Fig. 1** A Study area of Vu Gia-Thu Bon (VGTB) basin. (b) DEM and Hydro-meteorological stations

**Table 1** Statistical parameters of the 12 selected stations of the VGTB basin (1979–2018)

Station_Name	X (°)	Y (°)	Z (m)	$P_{max}$ (mm/d)	Average (mm/d)	Standard deviation (mm/d)	Variation coefficient (%)
Hien	107.646	15.917	535.00	482.2	6.0	19.6	31
Thanh My	107.833	15.767	136.00	621.9	6.2	19.9	31
Hoi Khanh	107.919	15.827	21.90	459.2	5.2	18.4	28
Ai Nghia	108.104	15.874	10.70	500.6	6.4	22.2	29
Cau Lau	108.279	15.860	2.00	541.9	6.0	21.5	28
Giao Thuy	108.127	15.839	11.00	480.6	6.4	21.9	29
Hoi An	108.365	15.870	4.43	666.6	6.0	22.1	27
Hiep Duc	108.102	15.578	38.30	689.0	8.3	26.4	32
Nong Son	108.033	15.700	22.50	513.3	8.3	24.6	34
Tien Phuoc	108.300	15.483	53.20	534.4	8.8	28.4	31
Tra My	108.233	15.350	142.00	782.4	11.4	32.1	36
Cam Le	108.206	16.013	10.70	594.5	5.9	22.0	27

X–longitude, Y–latitude, Z – elevation,  $P_{max}$ –highest daily precipitation noted in 1979–2018

per 700 km<sup>2</sup> (Table 1). Unfortunately, due to the rugged and inaccessible mountainous terrain in the western part of the VGTB basin, no stations were available in that area.

Figure 1b illustrates the location of the 12 rainfall stations used in this study.

According to the variation coefficients of annual maximum rainfall, which oscillate between 0.27 (27%) and 0.36 (36%) (Table 1), the annual maximum rainfall of the 12 stations of the VGTB basin does not show great variability.

### 3 Methodology

#### 3.1 Innovative trend analysis (ITA)

The innovative trend analysis was proposed by Şen (2012) (Şen 2012). The biggest advantage of this method is the fact that it does not require any assumptions (series correlation, non-normality, number of samples, etc.). The historical data on the monthly maximum rainfall was divided into two equal parts: 1979–1998 and 1999–2018. The two segments have been arranged in ascending order. The first sub-series  $x_i$  (first half) represented on the x-axis, while the other sub-series  $y_i$  (second half) shown on the y-axis. The two halves are plotted on a graph. If the data is plotted along the 1:1 line indicates that there is no trend in the series. A series shows an increasing trend if the data is plotted above the 1:1 line, and decreasing if it is below the 1:1 line (Vo et al. 2016; Şen 2012).

#### 3.2 Innovative trend analysis (ITA) method modified by Benzater et al. (2021a)

Studies on trends in intensity categories (hereafter categories) of daily maximum rainfall are few compared to total rainfall worldwide (McBride et al. 2022; Benzater et al. 2021a; Juliette et al. 2021; Caloiero et al. 2017; Yosef et al. 2009; Alpert et al. 2002). To analyze rainfall intensity, some authors (Benzater et al. 2021a; Caloiero et al. 2017; Yosef et al. 2009; Alpert et al. 2002) have proposed the categorization of daily totals into six categories: light: 0–4 mm/day (A); mild-moderate: 4–16 mm/day (B); moderate-heavy: 16–32 mm/day ( $C_1$ ); heavy: 32–64 mm/day ( $C_2$ ); heavy-torrential: 64–128 mm/day ( $D_1$ ) and torrential: greater than or equal to 128 mm/day ( $D_2$ ).

In this article, we aimed to analyze the trend of monthly maximum daily rainfall in the VGTB basin in central Vietnam from 1979 to 2018 using the ITA method proposed by Benzater et al. (2021a) with modifications which made the results clearer. For each of the 12 rainfall stations in the VGTB basin, we selected and categorized the monthly maximums of daily rainfall into six categories proposed by previous studies. The modified ITA method allowed us to identify the changes in trends for different categories of daily maximum rainfall on a monthly scale. The results of our study are presented in Fig. 2.

The improvements in the visualization of the results of the original ITA method made by Benzater et al. (2021a) are remunerated from 1 to 4:

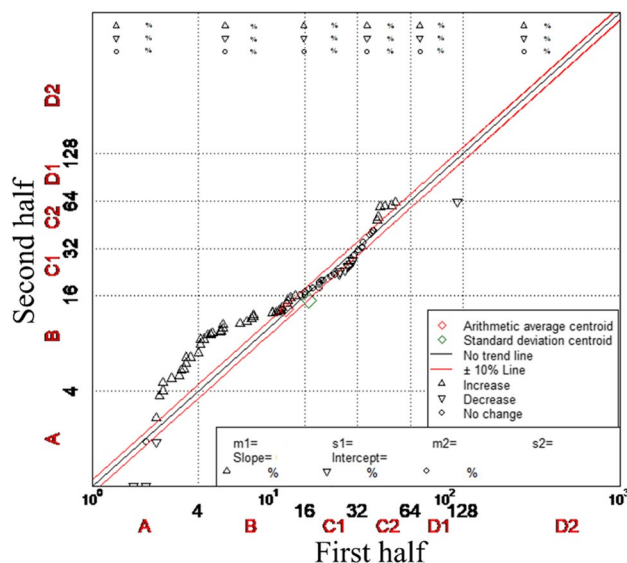


Fig. 2 Modified ITA method template (Benzater et al. 2021a)

- 1) The subdivision of the two axes X and Y of the graph according to the six categories adopted (A, B,  $C_1$ ,  $C_2$ ,  $D_1$ , and  $D_2$ ),
- 2) The ITA graph is transformed into a bi-logarithmic scale for better visibility of the values of the lower categories,
- 3) Symbols O,  $\Delta$ ,  $\nabla$  respectively representing no-trend, increasing and decreasing trends, including their displayed percentages, for each category, at the top of the figure (e.g., Fig. 2), have been introduced. Figure 2 is a simple template of the modified ITA graph. In the application of this modified ITA graph, the percentages are displayed (Fig. 3).
- 4) Two straight lines parallel below and above the 1:1 non-trend line was inserted on the graph indicating a minimum distance from this line to identify positive, negative and no trends. Each value in the 2nd half is considered increasing (decreasing) if it is higher (lower) than that of the 1st half plus (minus) 10% (Wu and Qian 2016). The 1<sup>st</sup> identifier (First half) corresponds to the X axis, then the 2<sup>nd</sup> (second half) corresponds to the Y axis (it is clear in Fig. 2). This modification transforms the visual interpretation of the initial ITA method into a numerical interpretation.

Finally, this new configuration of the ITA allows the detection of migration movements between categories. If a scatter point, from a given category on the x-axis, is on a different cell on the y-axis, it signifies a migration to the higher (lower) category (Benzater et al. 2021a). Migration movements do not appear on the initial ITA.

All calculations and maps in this study were conducted using programs written in R. To analyze trends in rainfall categories, we classified the six categories of monthly



January

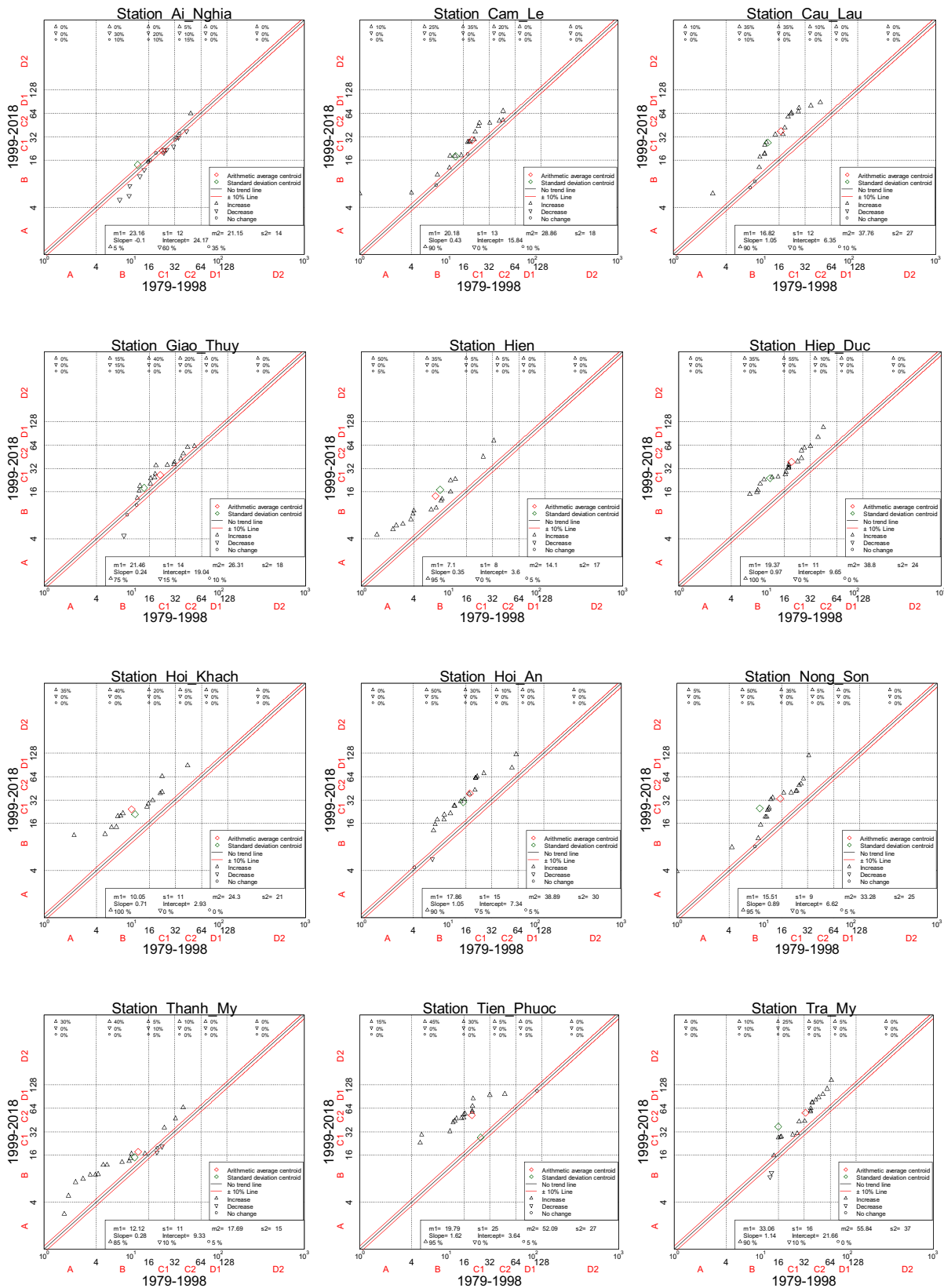


Fig. 3 Trends in monthly maximum precipitation categories identified by the ITA method modified by Benzater et al. (2021a, b) (1979–2018)

February

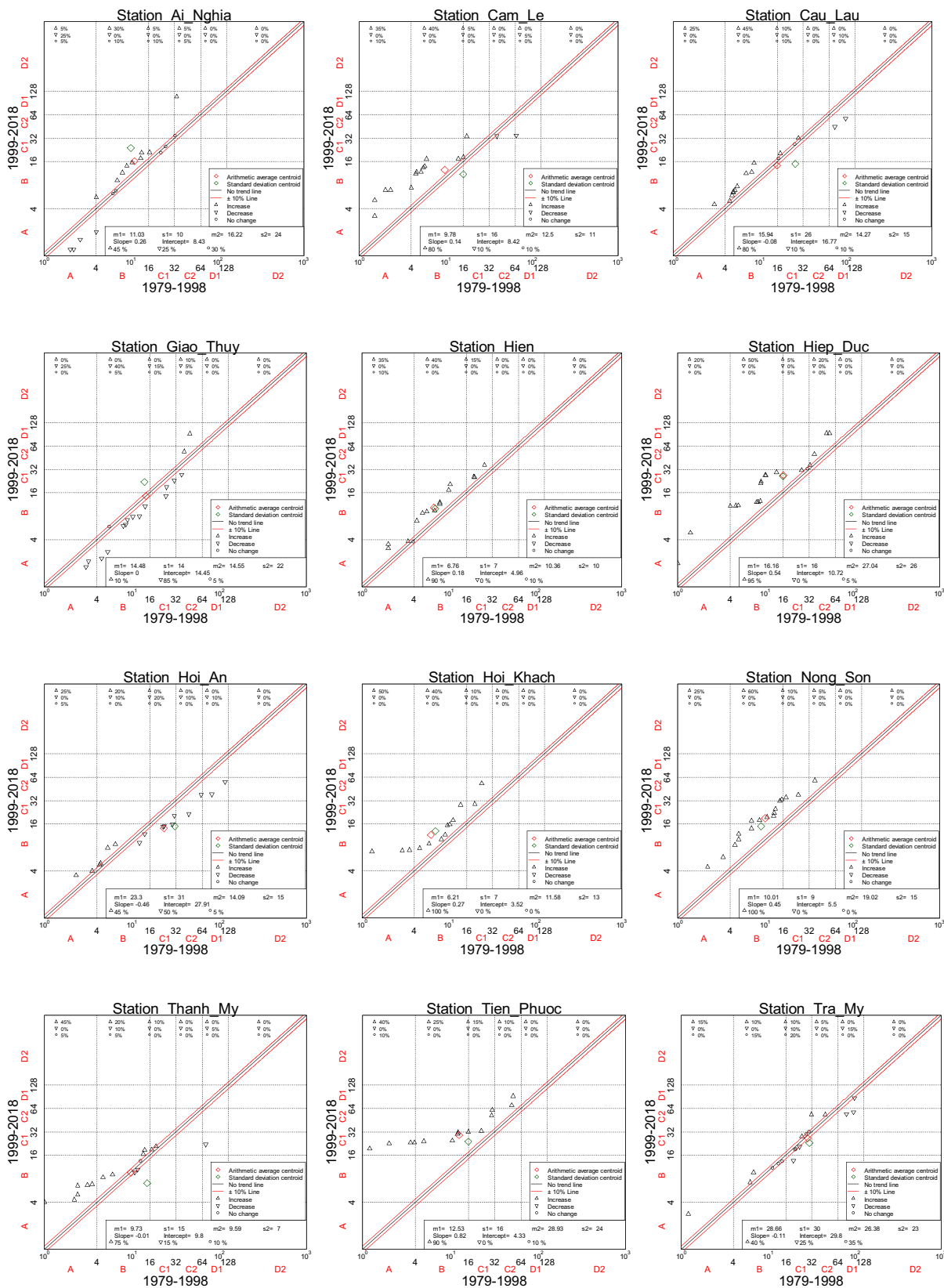


Fig. 3 (continued)

March

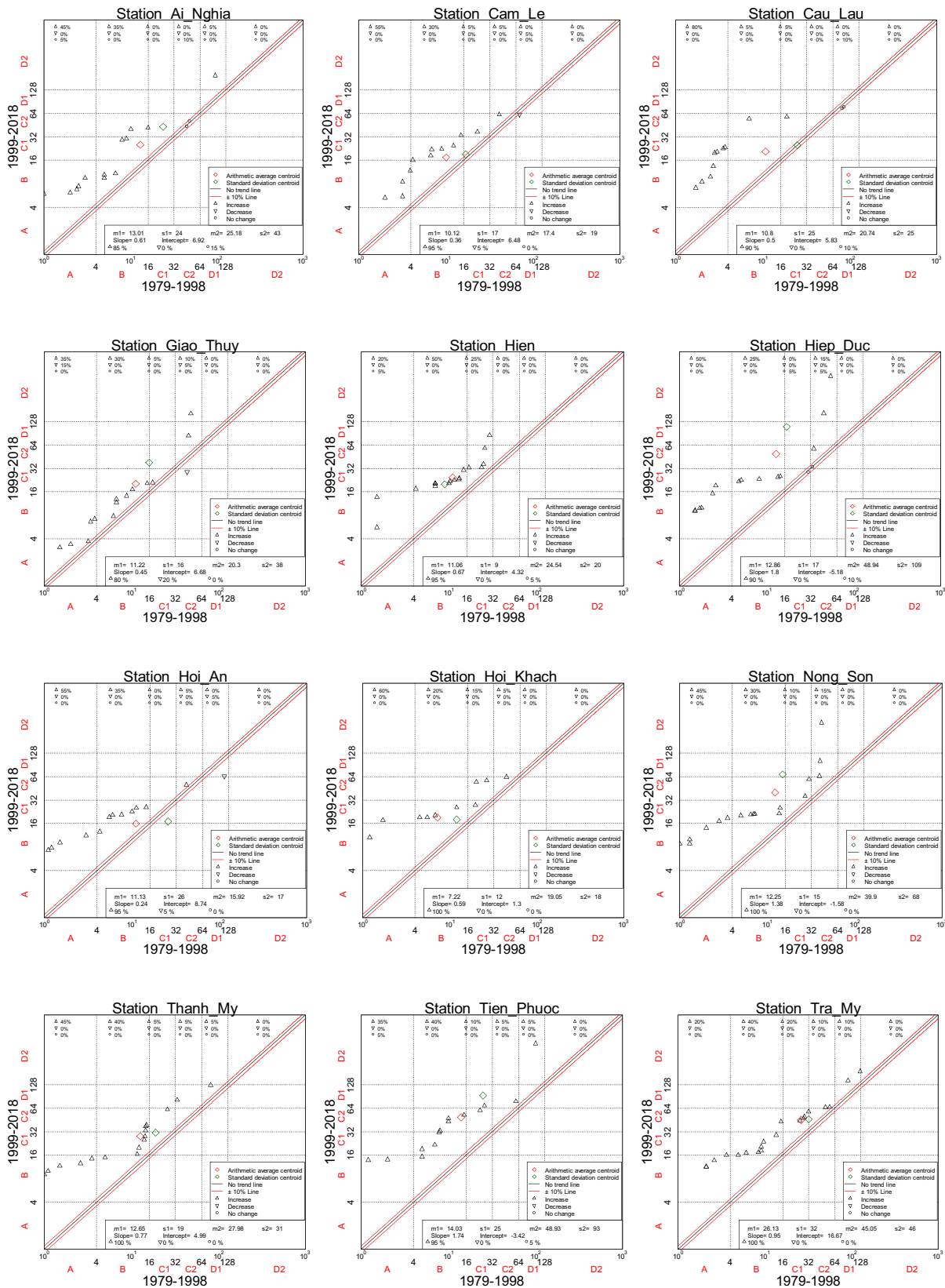


Fig. 3 (continued)

April

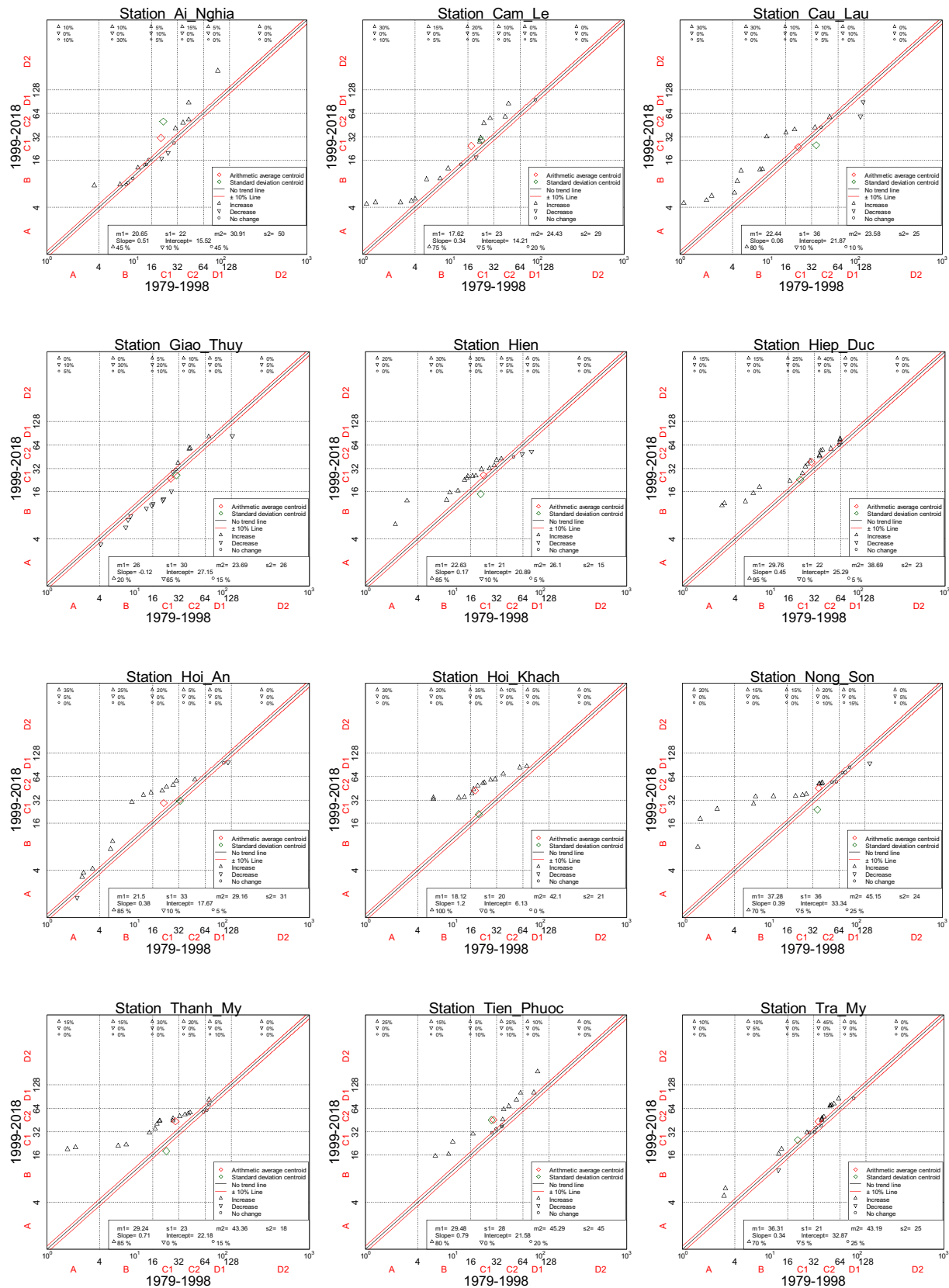


Fig. 3 (continued)

May

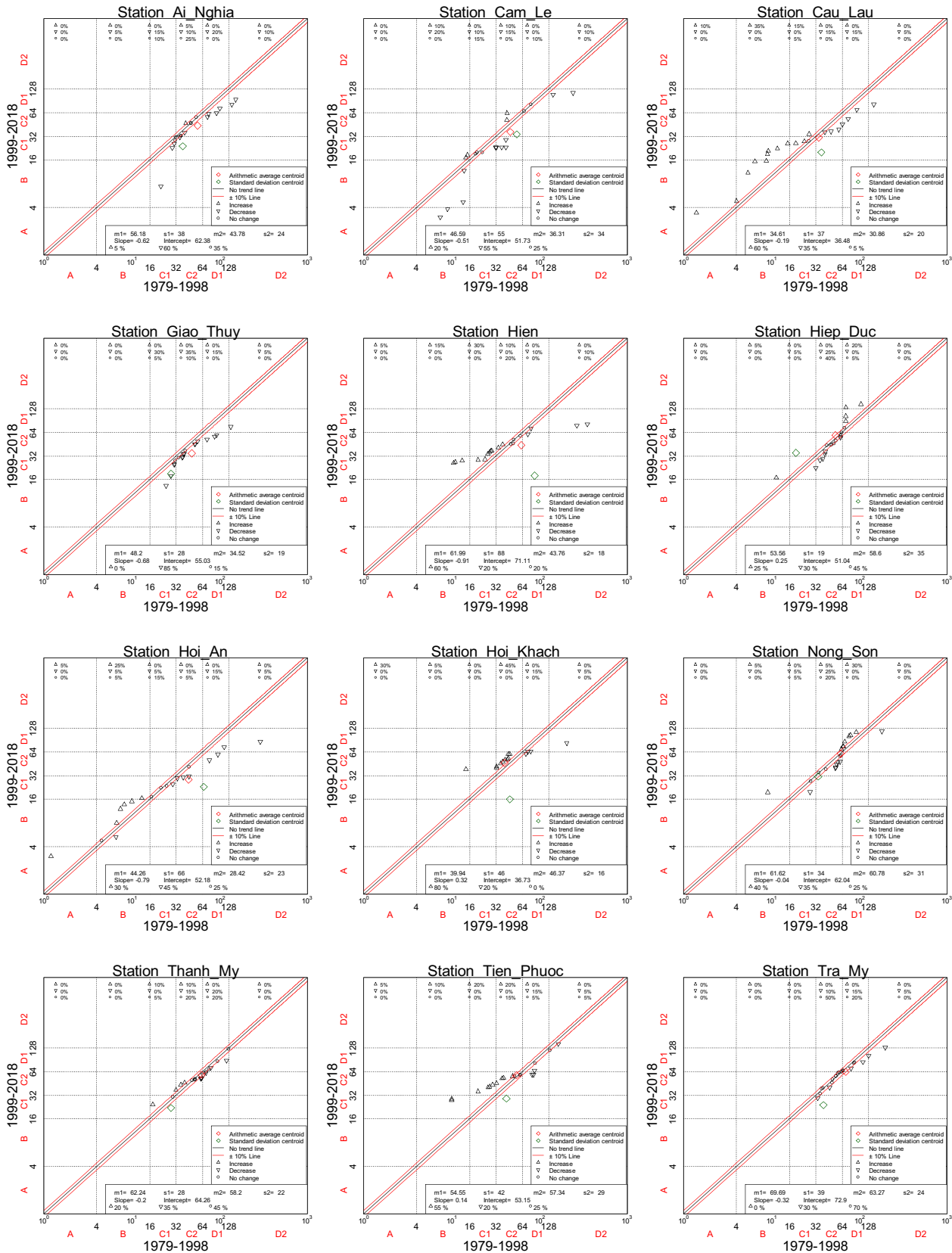


Fig. 3 (continued)



June

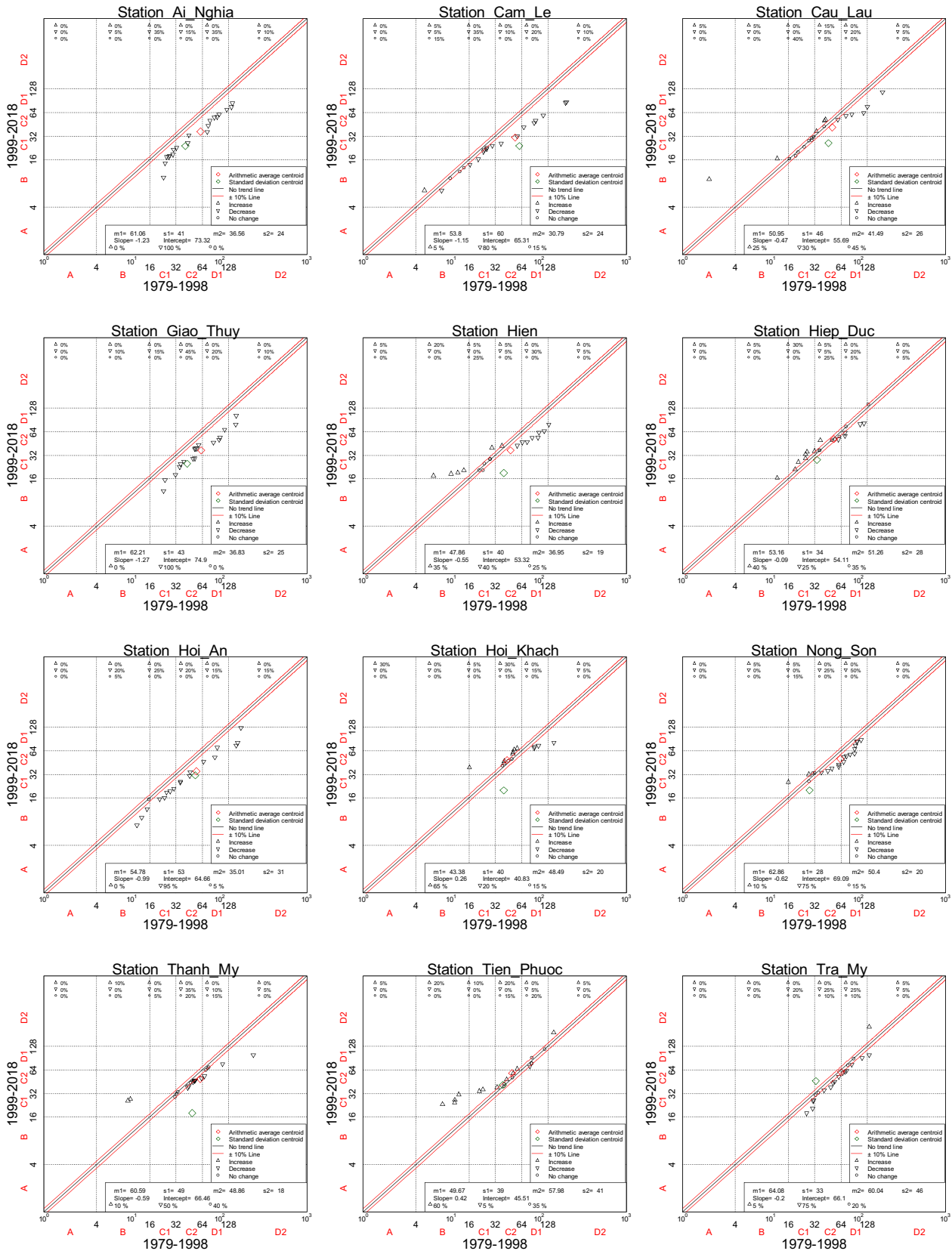


Fig. 3 (continued)

July

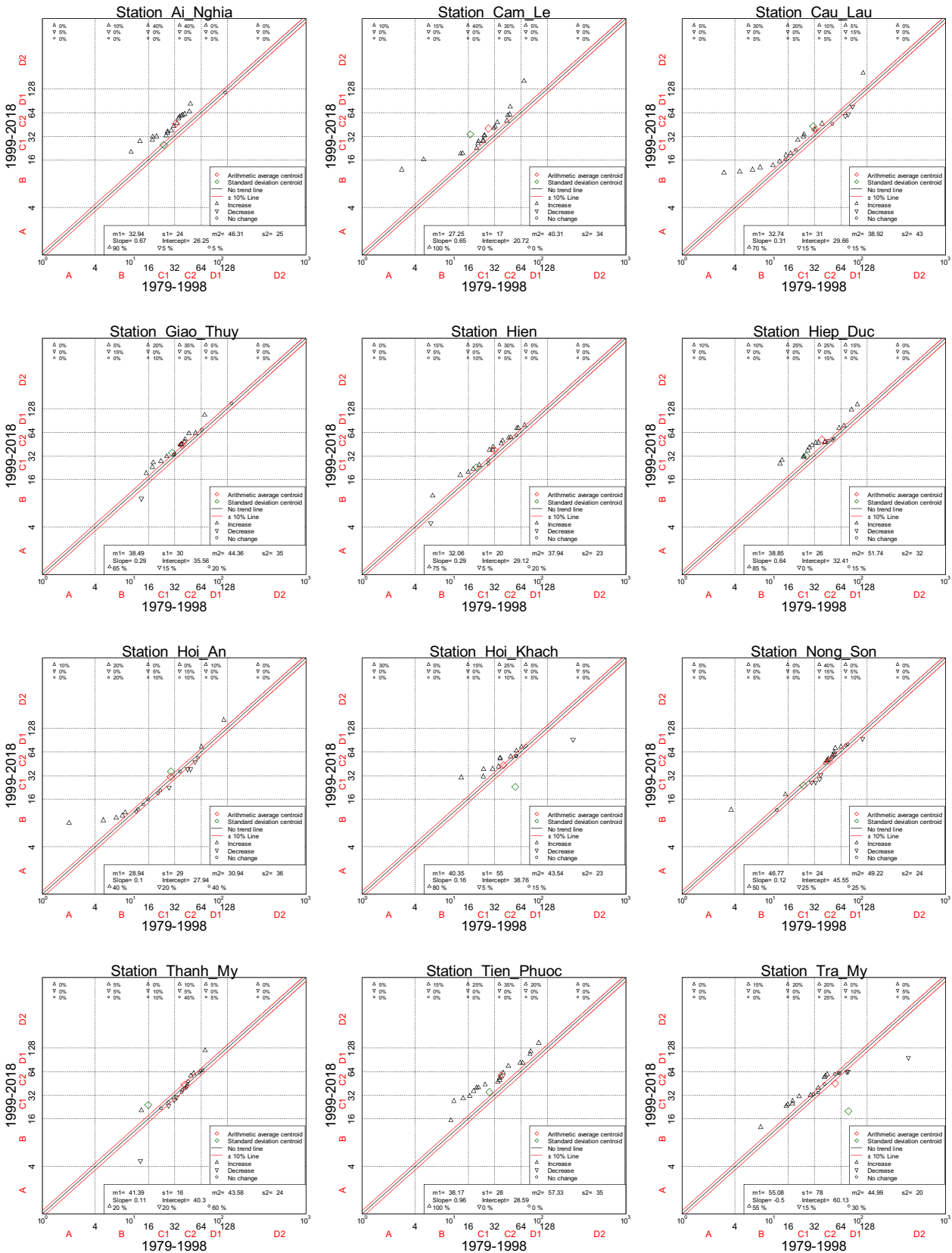


Fig. 3 (continued)

August

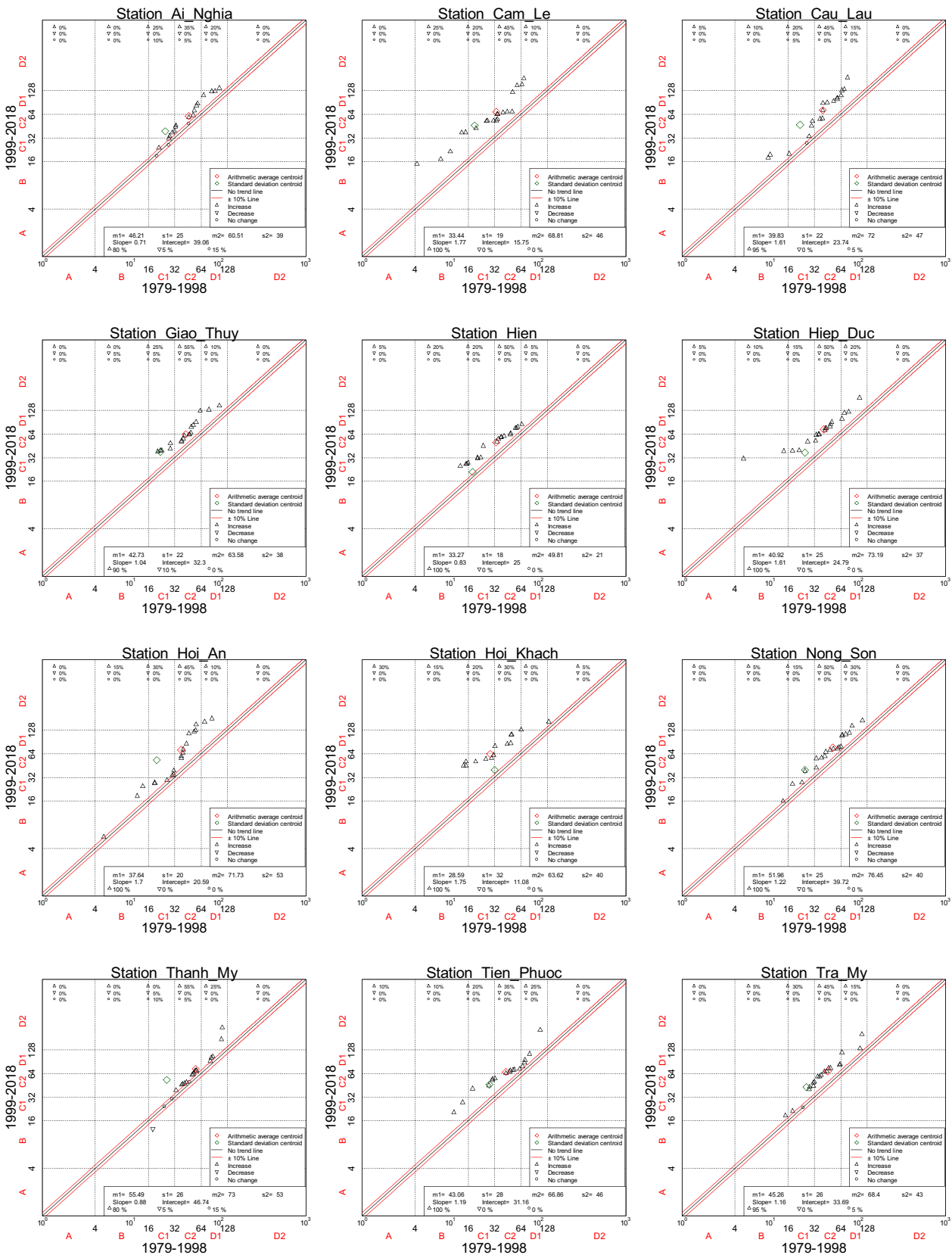


Fig. 3 (continued)

# September

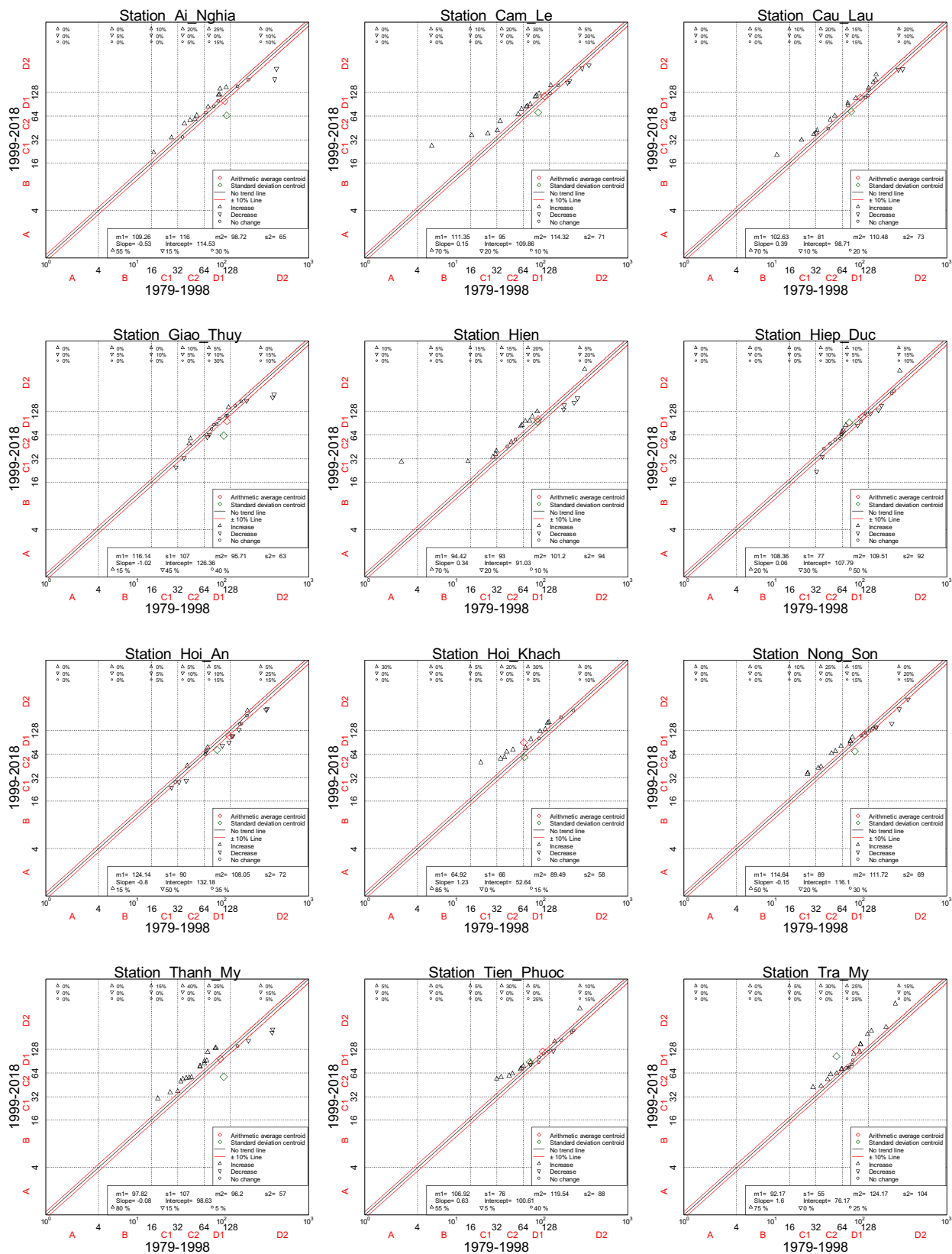


Fig. 3 (continued)

October

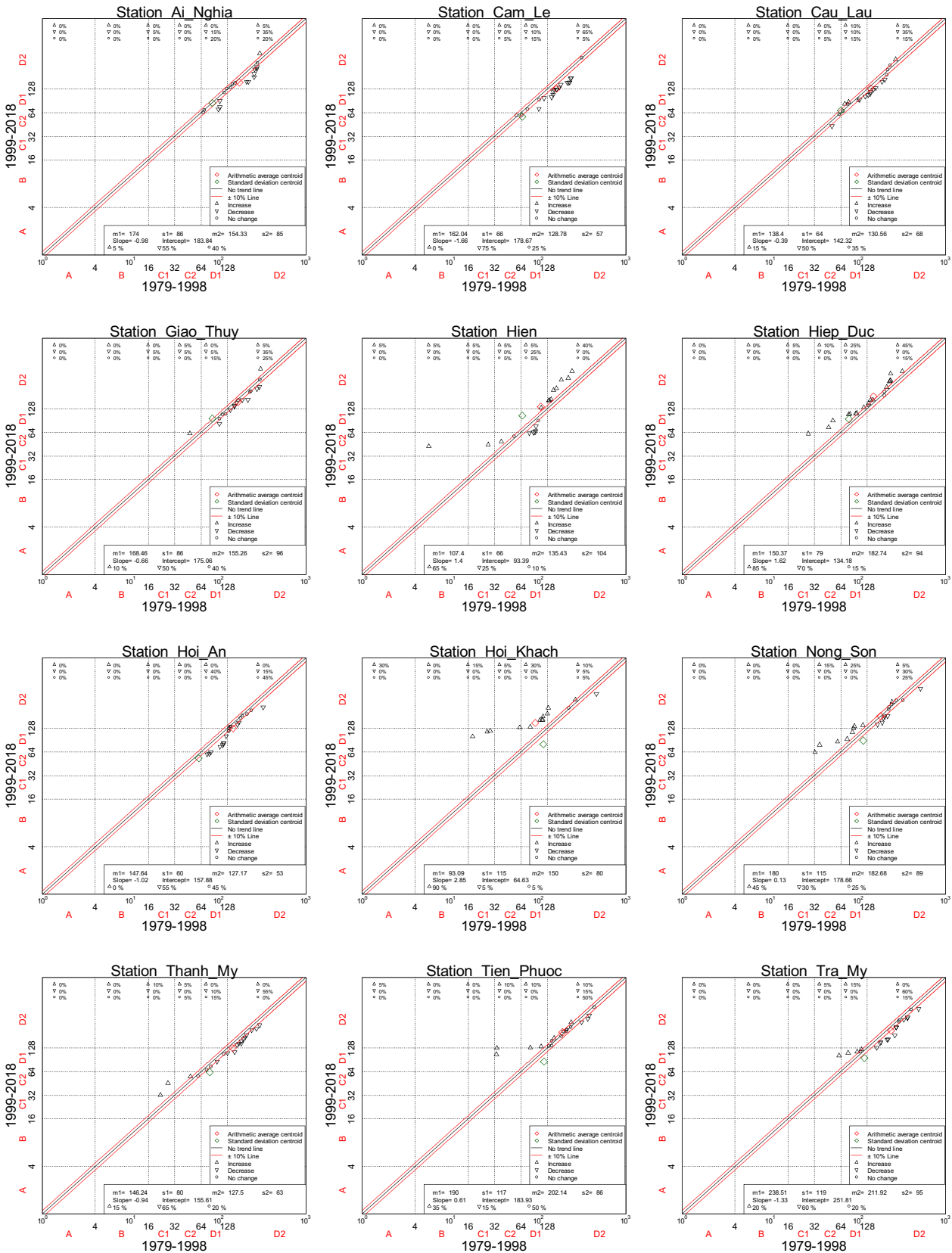


Fig. 3 (continued)



# November

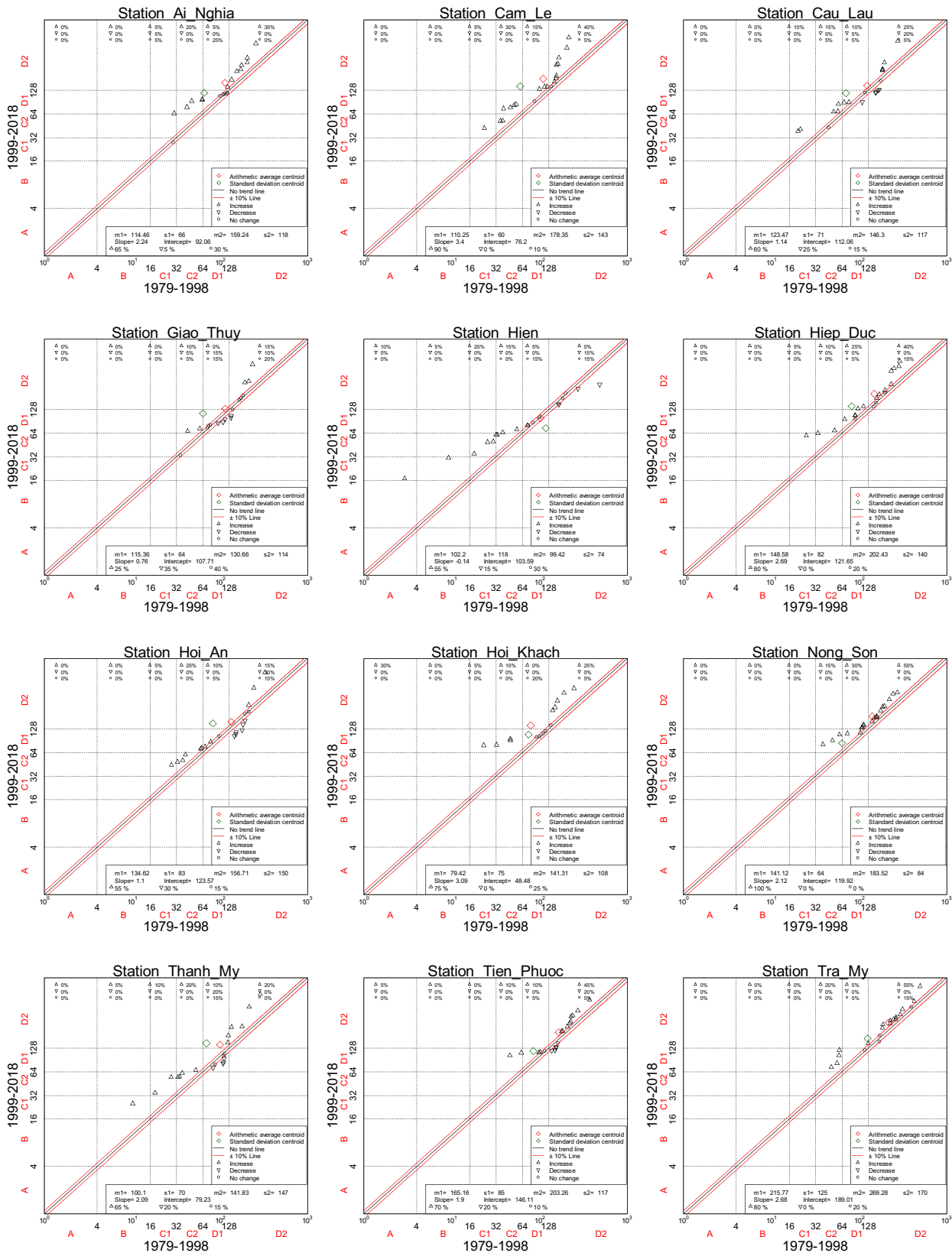


Fig. 3 (continued)

December

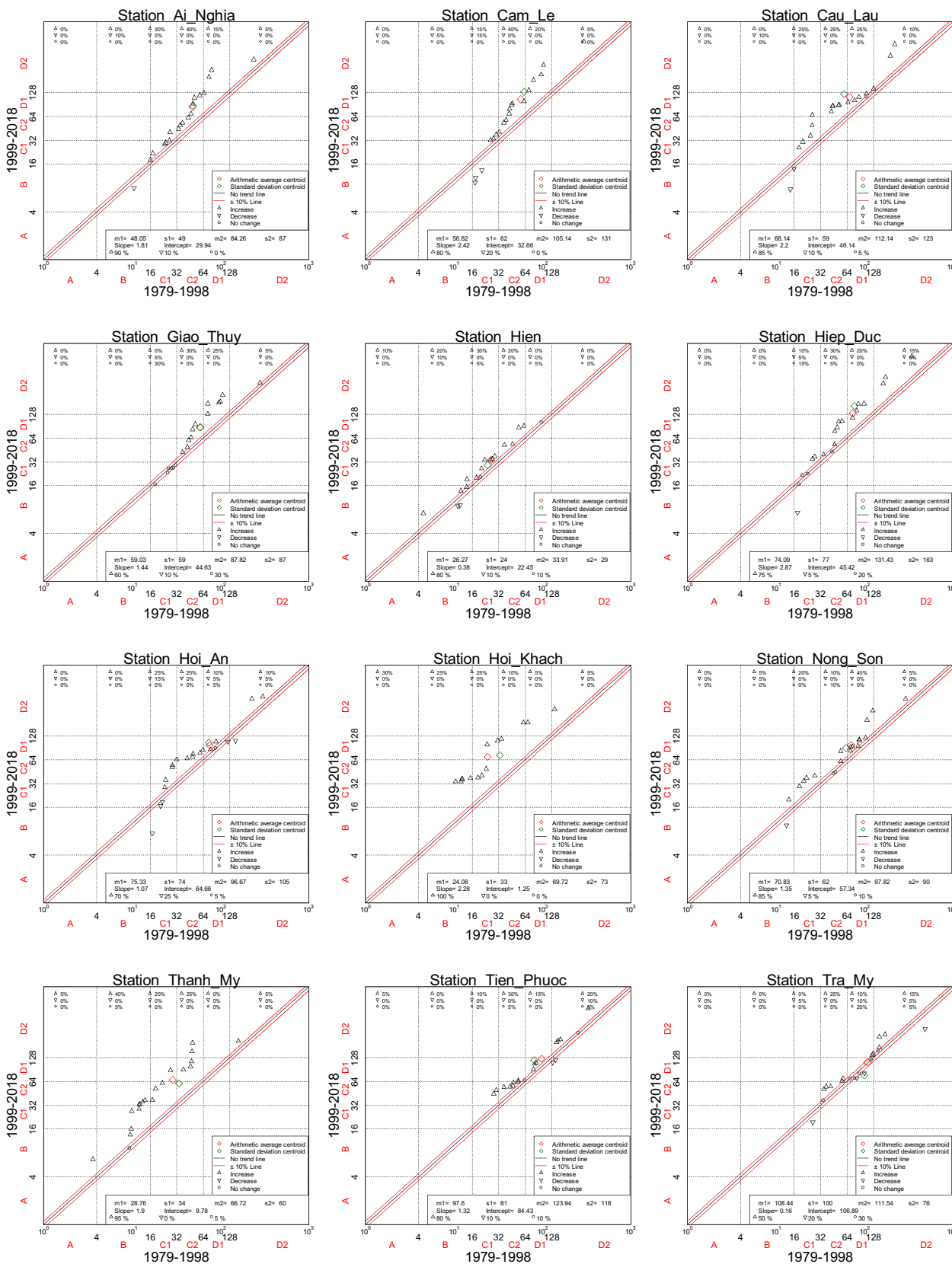


Fig. 3 (continued)

maximum rainfall from 12 selected stations in the VGTB basin between January 1979 and December 2018.

### 3.3 Factorial correspondence analysis (FCA)

Factorial correspondence analysis (FCA) is a method of multivariate inference widely used in hydrological research. This method makes it possible to analyze the influence of the

evolution of the weather (months of the year) on the behavior of the rain categories in an effective and efficient way (Wang et al. 2015). It reduces variables to a small number of independent orthogonal factors. Resulting from the calculations of a data similarity matrix, followed by a statistical transformation involving its digitization and extraction of the eigenvectors (the factorial axes) and the associated eigenvalues defining the explained fraction of the initial variance

**Table 2** Average values of monthly contributions (as a percentage of extreme rainfall events) for each category of daily maximum rainfall for the 12 stations in the VGTB basin

Station	Jan						Feb						Mar						Apr						May						June																	
	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>						
Hien																																																
Thanh My																																																
HoiKhach																																																
Ai_Nghia																																																
Cau_Lau																																																
Giao_Thuy																																																
Hoi_An																																																
Hiep_Duc																																																
Nong_Son																																																
Tien_Phuoc																																																
Tra_My																																																
Cam_Le																																																
Station	July						Aug						Sep						Oct						Nov						Dec																	
	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	A	B	C <sub>1</sub>	C <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>						
Hien																																																
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Cau_Lau																																																
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Tra_My																																																
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of the data (Pereira and Sousa 2000). In order to use factorial correspondence analysis (FCA), the initial matrices of codified data, served as input data for FCA, were transformed into contingency tables (Pereira and Sousa 2000). The contingency table represents the frequencies of co-occurrence of classes of response variables with classes of selected explanatory variables. Then, the table is submitted to FCA and in principle only the first factorial axis extracted is retained, provided that it explains a significant part of the initial variance of the data (Pereira and Sousa 2000; Brown 1998; Stigter et al. 2008).

This analysis (FCA) was applied to the results obtained in this study to show the existence of possible links between each category of monthly maximum in daily rainfall and the different months of the year.

## 4 Results and discussion

To understand the historical behavior of maximum daily rainfall in the VGTB basin, it is essential to calculate the contributions (as a percentage of frequencies) of the six categories of maximum daily rainfall for each month during the 40-year observation period (1979–2018) (as presented in Table 2) before analyzing trends (Caloiero et al. 2017).

The contribution of different categories of maximum daily rainfall events during different months related to unequal distribution of precipitation during a year (Table 2). The intensity of color in this table represents the magnitude of the corresponding numerical values, with darker colors indicating larger values and lighter colors indicating smaller values. The mild-moderate category B (40%) was found to be the highest contributor during January and February. In

March and April, the light category A was dominant with 48% and 24% of daily rainfall events, respectively. The highest contribution was observed in the heavy category ( $C_2$ ) during the months of May to August, with 40%, 30%, 38%, and 46%, respectively. The upward trend in contributions continues for the month of September affecting the heavy-torrendial category ( $D_1$ ) with 33%. Torrendial rains ( $D_2$ ) appeared in October and November, accounting for 58% and 47%, respectively. Finally, the highest contribution for the month of December was observed in the heavy-torrendial category ( $C_2$ ) with 28%.

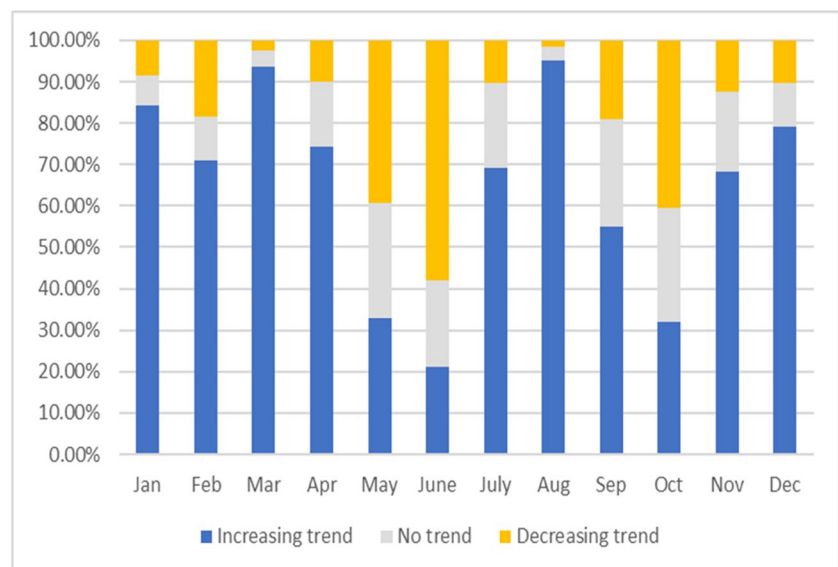
### 4.1 New approach to ITA modified by Benzater et al. (2021a)

The matrix product of 5760 total rainfall events (12 months, 12 stations) resulted in 40 monthly maximum events, with each ITA graph representing 20 events per half. This approach allowed us to gain a comprehensive understanding of rainfall trends across the region over the past 40 years.

The modified ITA method, developed by Benzater et al. (2021a), has been applied to the monthly maximum daily rainfall data collected at 12 meteorological stations in the VGTB basin. This approach allows for clear visualization of the temporal and spatial behavior of this type of rainfall throughout the year (1979–2018) (refer to Fig. 3). For the purpose of a concise presentation, Fig. 3 only displays trends from January to April. The detailed results for the remaining months can be found in the Supplementary information.

The analysis of Fig. 4, taken from the results of Fig. 3, shows the overall trends in monthly maximum daily rainfall for the 12 stations in the VGTB basin during the period 1979–2018. On the time scale, Fig. 4 and Table 3 show

**Fig. 4** Trends in monthly maximum daily rainfall (%) (1979–2018)







**Table 3** (continued)

	D <sub>1</sub>	5%	25%	5%	0%	10%	15%	30%	0%	0%	0%	15%	20%	10%	10%	15%	0%	5%	15%	0%	40%	0%	25%	0%	0%	25%	0%	0%	10%	0%	0%	15%	0%	5%	0%	10%	15%	10%	10%	29%	10%	8%	
	D <sub>2</sub>	40%	0%	0%	0%	55%	0%	10%	5%	5%	5%	35%	20%	5%	35%	15%	5%	35%	25%	0%	15%	45%	45%	0%	15%	5%	30%	25%	10%	15%	50%	0%	60%	15%	0%	65%	5%	10%	29%	18%			
Nov	A	10%	0%	0%	0%	0%	0%	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	0%	
	B	5%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%
	C <sub>1</sub>	20%	0%	0%	10%	0%	0%	5%	0%	0%	5%	5%	5%	10%	0%	0%	0%	5%	0%	5%	0%	5%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	5%	1%	0%
	C <sub>2</sub>	15%	0%	0%	20%	0%	0%	15%	0%	0%	20%	0%	0%	15%	0%	5%	10%	5%	5%	25%	0%	0%	10%	0%	0%	15%	0%	0%	20%	0%	0%	30%	0%	0%	0%	0%	0%	0%	0%	17%	0%	1%	
	D <sub>1</sub>	5%	0%	15%	10%	20%	15%	0%	0%	20%	5%	0%	25%	10%	5%	5%	0%	15%	15%	10%	0%	5%	25%	0%	5%	30%	0%	0%	10%	0%	5%	5%	0%	5%	15%	0%	5%	10%	3%	10%			
	D <sub>2</sub>	0%	15%	15%	20%	0%	0%	25%	0%	5%	35%	0%	0%	25%	20%	5%	15%	10%	20%	15%	30%	10%	40%	0%	15%	55%	0%	0%	45%	20%	5%	55%	0%	15%	40%	0%	5%	4%	8%	8%			
Dec	A	10%	0%	0%	5%	0%	0%	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	0%	0%	
	B	20%	10%	0%	40%	0%	5%	25%	0%	0%	0%	10%	0%	0%	10%	0%	0%	5%	0%	0%	0%	0%	0%	0%	0%	5%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	8%	4%	0%
	C <sub>1</sub>	30%	0%	5%	20%	0%	0%	25%	0%	0%	30%	0%	0%	25%	0%	0%	0%	5%	30%	25%	15%	0%	10%	5%	15%	20%	0%	0%	10%	0%	0%	0%	0%	5%	0%	15%	15%	0%	18%	4%	4%		
	C <sub>2</sub>	20%	0%	0%	25%	0%	0%	10%	0%	0%	40%	0%	0%	25%	0%	0%	30%	0%	0%	25%	0%	0%	30%	0%	5%	10%	0%	10%	30%	0%	5%	25%	0%	5%	40%	0%	0%	0%	0%	0%	0%	2%	
	D <sub>1</sub>	0%	0%	5%	0%	0%	0%	5%	0%	0%	15%	0%	0%	25%	0%	5%	25%	0%	0%	10%	5%	5%	20%	0%	0%	45%	0%	0%	15%	0%	0%	10%	10%	20%	20%	0%	0%	16%	1%	3%			
	D <sub>2</sub>	0%	0%	0%	5%	0%	0%	5%	0%	0%	0%	0%	10%	0%	0%	0%	5%	0%	0%	10%	5%	0%	15%	0%	0%	5%	0%	0%	20%	10%	5%	15%	5%	5%	5%	5%	0%	0%	8%	2%	1%		

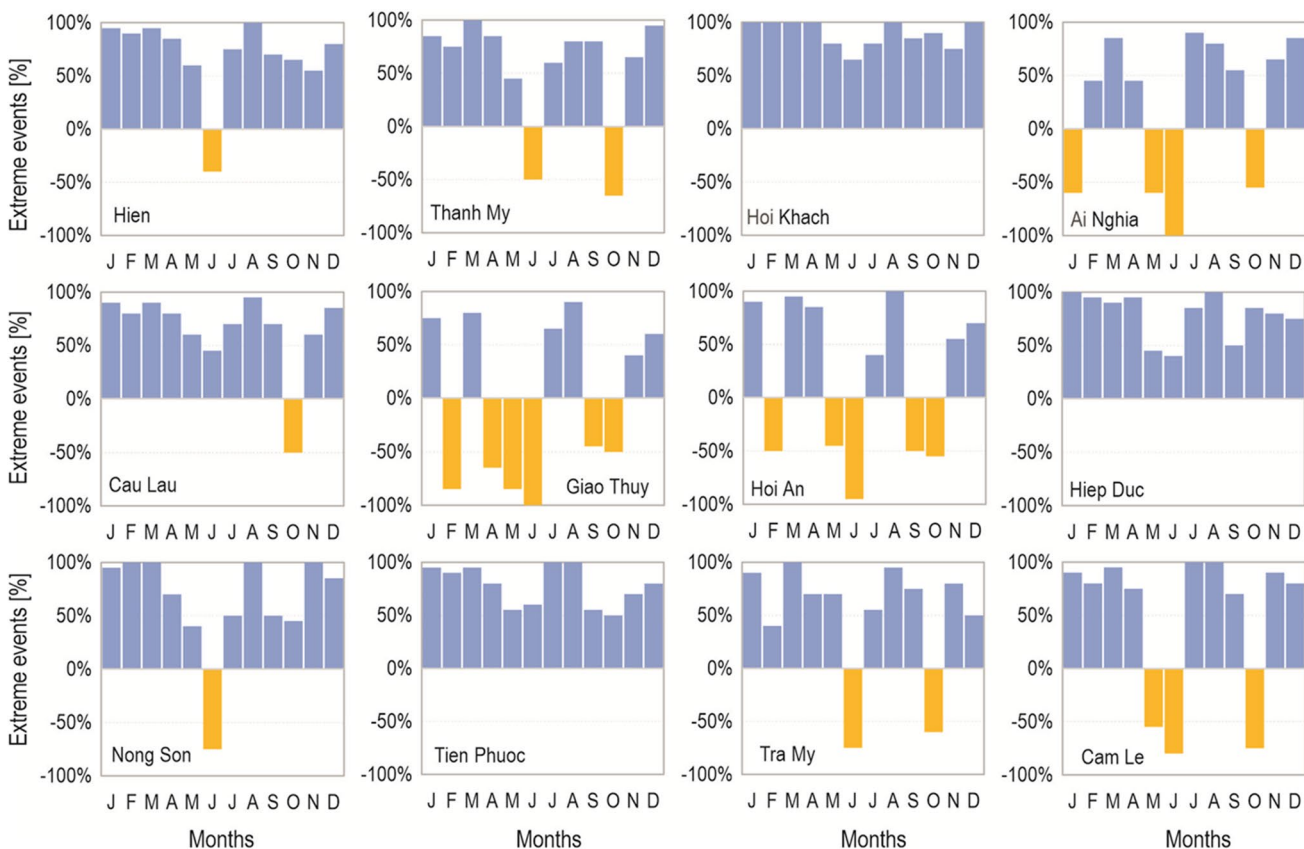
▲ Increasing trend ▼ Decreasing trend ○ No trend

impacted the majority of stations throughout the year. Hoi Khach, Hiep Duc, and Tien Phuoc stations show an increasing trend in all months. On the other hand, the decreasing trend was only observed in the stations of Ai Nghia (January (−60%), May (−60%), June (−100%) and October (−55%), Giao Thuy (February (−85%), April (−65%), May (−85%), June (−100%), September (−45%) and October (−50%)) and Hoi An (February (−50%), May (−45%), June (−95%), September (−50%) and October (−55%)). These results are consistent with several other studies such as Şan

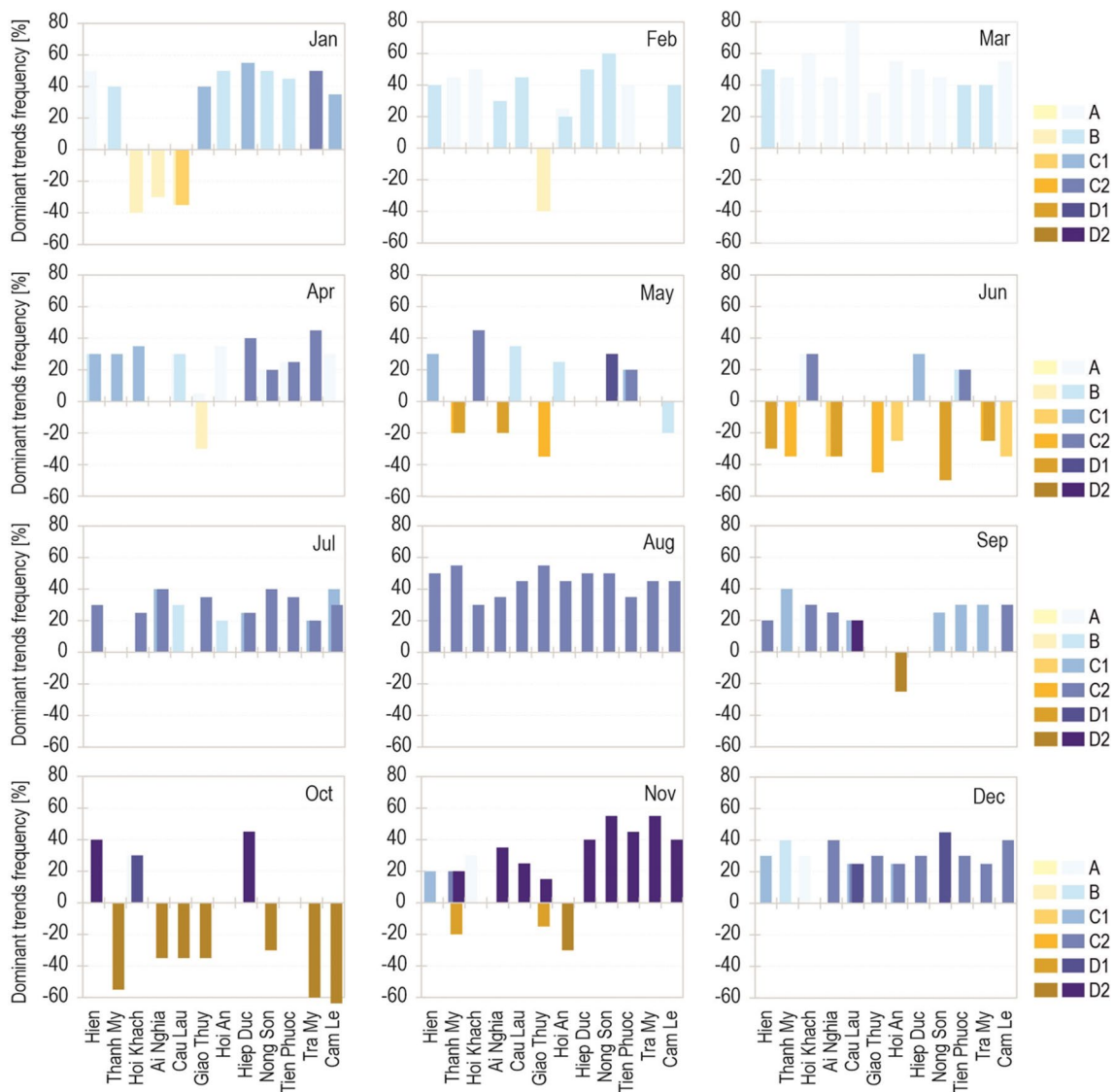
et al. (2021) (Murat et al. 2021) who studied total rainfall in Vietnam, Quan et al. (2021) (Spatiotemporal trend analysis of precipitation extremes in Ho Chi Minh City 2021) who researched extreme rainfall in Ho Chi Minh City, Vietnam, and Raghavan et al. (2017) (Raghavan et al. 2017) who projected extreme rainfall in Vietnam.

Figure 6 summarizes the results included in Table 3.

After analyzing Fig. 6, the trend in the monthly maximum of daily rainfall was examined. The dominant category varied across different months and stations. In



**Fig. 5** Trend frequency in monthly maximum daily rainfall (1979–2018), blue — frequency of increasing trends, orange — frequency of decreasing trends between months

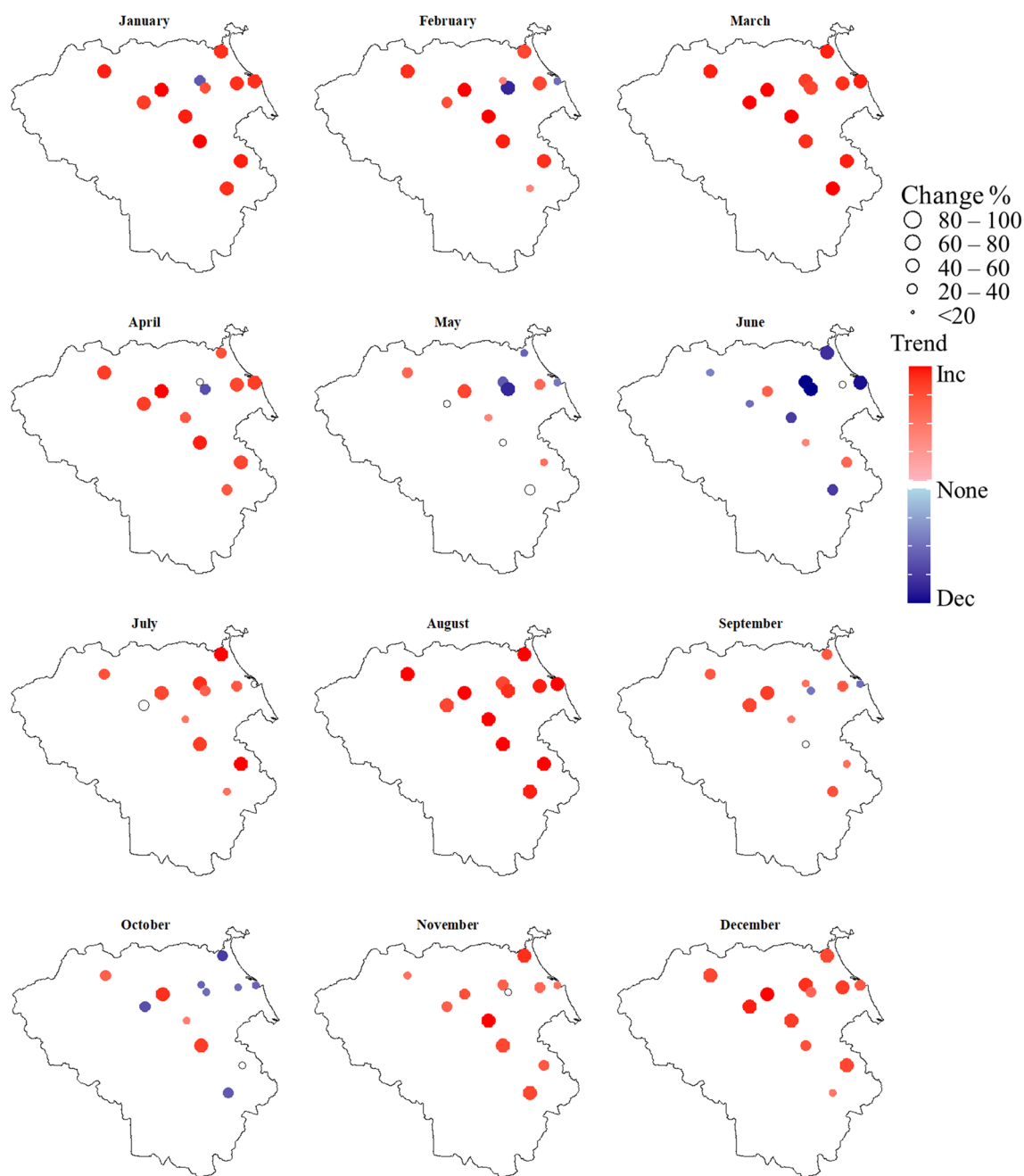


**Fig. 6** Dominant frequency of category trends in monthly maximum daily rainfall (1979–2018), the overlapping bars indicate that more than one category was dominant

January and February, the light-moderate category (B) was dominant, accounting for 32% of rainy events. March was dominated by the light category (A) with 45%. For July, the moderate-heavy category ( $C_1$ ) was dominant with 25% of rainy events. In August and September, the heavy category ( $C_2$ ) was dominant for all stations, accounting for 45% and 20% of rainy events, respectively. Finally, the heavy-torrential ( $D_1$ ) category was observed on the majority of the stations during December with 26% of events, and the torrential ( $D_2$ ) category was observed during November with 31% of events.

Only 3 months showed a downward trend. For the month of May, the heavy category ( $C_2$ ) was dominant with –17%,

the intense torrential category ( $D_1$ ) was dominant during the month of June with –22% of extreme rainy event and the torrential category ( $D_2$ ) was marked during the month of October with –29% (Fig. 6). It was observed that the dominance of categorical increasing trends progressed from January to December, with heavy rains typically occurring between May and November. At the spatial scale, most stations showed an increasing trend in monthly maximum daily rainfall categories. Specifically, the strongest affected categories were B,  $C_1$ ,  $C_2$ , and  $D_1$ , and these were located in western stations within the VGTB basin, including Hien, Thanh My, Nong Son, Hiep Duc, and Tra My.

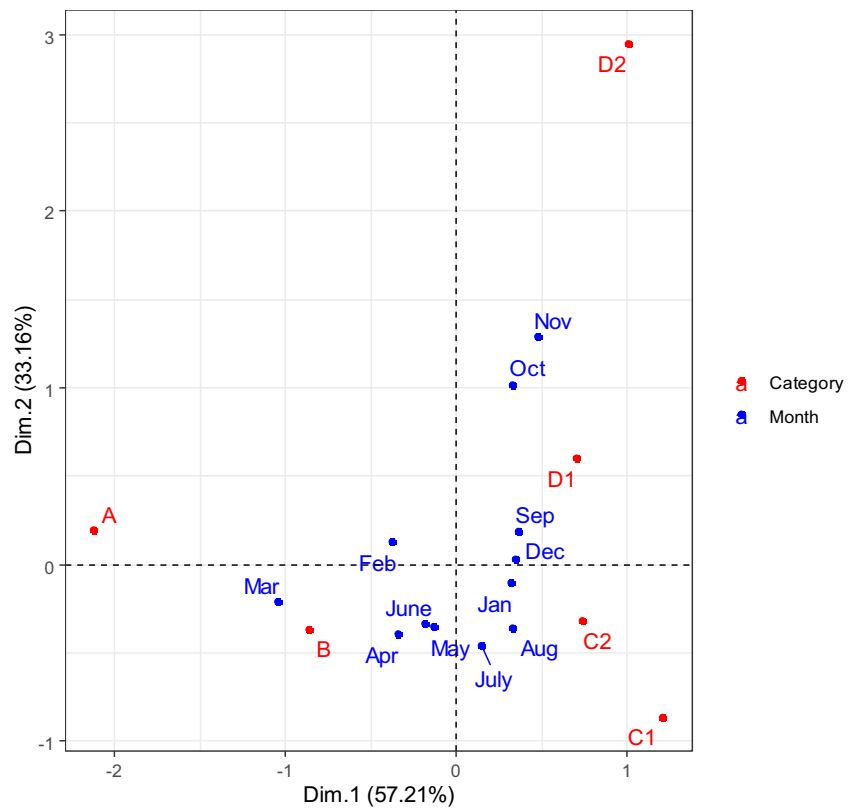


**Fig. 7** Spatial trends of monthly maximum rainfall categories of the VGTB basin (1979–2018)

The analysis provides valuable insights into the different categories of monthly maximum daily rainfall, highlighting the variation across different months and stations. By identifying the dominant categories, the study sheds light on the intensity and frequency of extreme rainfall events in the region (Fig. 7). This information can contribute to a better understanding of the overall patterns and trends in extreme rainfall in central Vietnam

and may aid in the development of effective measures to mitigate the impacts of such events. Quan et al. (2021) (Spatiotemporal trend analysis of precipitation extremes in Ho Chi Minh City 2021) showed that El Nino-Southern Oscillation and the Pacific Decadal Oscillation are positively correlated with the duration and negatively with the intensity and frequency of extreme precipitation events.

**Fig. 8** Temporal relationship of increasing trends of extreme rainfall categories with the 12 months of the year (VGTB: 1979–2018)



## 4.2 Factorial correspondence analysis

To better understand the increasing trend behavior of the categories in relation to the months of the year, we performed a factorial correspondence analysis (FCA) between the six categories having only an increasing trend (1862 events increasing rains extreme) in the 12 months of the year (Fig. 8). The light-moderate category (B) experiences an increase in extreme rainfall trend for the months of February and March with 2.85%, and April (2.15%) and during the research period. The moderate-heavy category ( $C_1$ ) with 2.47% did not show a clear position regarding the months. The heavy category ( $C_2$ ) is well correlated with the months of August (5.80%) and July (3.32%). The heavy-torrential category ( $D_1$ ) intensifies during the month of September (2.26%) and December (2.04%), while the highest torrential category ( $D_2$ ) manifests itself timidly during the month of November with 3.87% of extreme rainfall events occurring throughout the year.

It is clear in Fig. 8 that the two most extreme categories (A and  $D_2$ ) are more or less distant from the months of the year compared to the four categories (B,  $C_1$ ,  $C_2$ , and  $D_1$ ) which are very marked.

The results of the factorial correspondence analysis (FCA) on the monthly maximum rainfall showing only an increasing trend in relation to the months of the year are in correspondence with the monthly contributions of each category (Table 2).

## 5 Conclusion

This article analyzes the trends of monthly maximum daily rainfall categories in the VGTB basin (central Vietnam) during the period of observation from 1979 to 2018. The modified ITA method by Benzater et al. (2021a) was applied to analyze the monthly maximum of daily precipitation records collected from 12 stations. The main findings of this study are as follows:

The analysis indicates an overall increasing trend in the monthly maximum of daily rainfall for the 12 stations in the VGTB basin during the period of observation. Extreme monthly rainfall events have shown a growing trend in 75% (9/12) of the months, namely January (84%), February (71%), March (94%), April (74%), July (69%), August (95%), September (55%), November (68%), and December (79%).

The temporal analysis of the trends of the categories of monthly maximum rainfall shows that the light-moderate category (B) has a dominant increasing trend (32%) for all the stations during the months of January (5.85% of rainy events) and February (3.44%). The light category (A) is dominant, compared to the rest of the categories, for the months of March and April with 45% and 20% respectively. In July, the moderate-heavy category ( $C_1$ ) is dominant in 25% of stations. The heavy category ( $C_2$ ) prevails over all stations for the months of August and September with 45% and 20% respectively. The heavy-torrential ( $D_1$ ) category

was observed at all stations during December, accounting for 26% of events, while the torrential ( $D_2$ ) category occurred in November, accounting for 31% of events.

These results indicate an increasing trend in the categories (B (4–16 mm/d),  $C_1$  (16–32 mm/d),  $C_2$  (32–64 mm/d), and  $D_1$  (64–128 mm/d)), which are consistent with previous studies that suggest an intensification of extreme rainfall events in various regions of the world.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s00704-023-04702-y>.

**Author contribution** Benali Benzater—Conceptualization, Writing—original draft, Software, Formal analysis, Visualization. Abdelkader Elouissi; Ewa Łupikasza; Abdelkader Harizia and Sahnoun Fellah—Data curation, Formal analysis; Writing—original draft, Visualization, Writing, Review and editing, Supervision. Quoc Bao Pham: Formal analysis, Writing—original draft, Visualization, Writing, Review and editing, Supervision.

**Data availability** The data that support the findings of this study are available from the author. [Quoc Bao Pham, quoc\_bao.pham@us.edu.pl], upon reasonable request.

## Declarations

**Competing interests** The authors declare no competing interests.

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