Daily precipitation concentration in Central Coast Vietnam

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Abstract
Empirical frequency distribution of daily precipitation amounts can be fitted by a negative exponential distribution, because anywhere there are many small daily totals and few large ones. Therefore, the cumulative percentages of days with precipitation, sorted in increasing order according to their amounts, against the cumulative percentage of the rainfall amounts that they contribute are fitted by positive exponential curves $Y = aXe^{bx}$, $a$ and $b$ constants. Based on these curves, the Concentration Index (CI) evaluates the contribution of the rainiest days to the total amount. In this study the CI has been calculated for 15 meteorological stations in Da Nang city and Quang Nam province in Central Coast Vietnam, for the 1979–2016 period. The results show high values of CI, ranging from 0.62 to 0.72. Conversely, the linear correlation between altitude and CI is negative ($R = -0.60$, $p < 0.01$). There are no correlations between the latitude nor the annual mean number of precipitation days and the CI. CI change for the sub-periods of 1979–1997 and 1998–2016 is also analyzed.

Keywords Concentration Index · Daily precipitation · Correlation · Monsoon climate · Vietnam

1 Introduction
The analysis of precipitation in a daily resolution is a subject of great climatic and environmental interest since the irregularity and concentration of rainfall is linked to a lot of phenomena as runoff, floods, drought, soil erosion, water resources, aquifer recharge etc. In all climates, heavy rainfall is concentrated in a few days per year, so the appearance or not of these days can change the character, dry or rainy, of a year. It is not uncommon that after several dry months a few very rainy days totalize more than normal amount. Water management and territorial planning should take into account the daily precipitation concentration for a better territory planning.

The concentration of daily precipitation has been recently studied in different countries and regions, even on a global scale. The main methodological approach for evaluating it is the Concentration Index (CI) proposed by Martin-Vide (2004). The CI has been calculated for Peninsular Spain and Spain (Martin-Vide 2004; Serrano-Notivoli et al. 2018), Iran (Alijani et al. 2008), Pearl River basin and Xinjiang (China) (Zhang et al. 2009; Li et al. 2011), central Andes of Peru (Zubieta and Saavedra 2009), Europe (Cortesi et al 2012), Peninsular Malaysia (Suhaila and Jemain 2012), Southern Italy (Coscarelli and Caloiero 2012), New Zealand (Caloiero 2013), Chile and Central-Southern Chile (Sarricolea and Martin-Vide 2014; Sarricolea et al 2019), Algeria and North-east of Algeria (Benhamrouche et al. 2015; Bessaklia et al. 2018), northern Morocco (Salhi et al. 2019), USA (Royé and Martin-Vide 2017), Argentina (Llano 2017), Southeastern Brazil (Nery et al. 2017), Southern Russia (Vyshkovskaya et al. 2018), Puerto Rico (Vélez et al. 2018) among others, and finally at a global scale (Monjo and Martin-Vide 2016).

The analysis of the daily precipitation concentration has special interest in the intertropical zonewhere heavy rains and showers are frequent. They can cause landslides, heavy soil leaching and other damages particularly in Southeastern Asia with rainy tropical climates and a high population density. This article focuses on the central coast of Vietnam, specifically Da Nang city and Quang Nam province.
The article is organized as follows: Section 2 establishes the objectives and shows the methodology; the data and the study area are described in Section 3; the results are detailed in Section 4 and are then discussed in Section 5; finally, the conclusions are in Section 6.

2 Objectives and methodology

The main aim of this study is to evaluate the daily concentration of precipitation in Central Coast Vietnam, i.e., evaluate the weight of the rainiest days to the annual total. The specific objectives are as follows: 1) calculate the values of the CI for 15 meteorological stations covering the study area; 2) establish the spatial patterns of the CI (correlations with latitude, longitude and altitude); and 3) compare the CI of the two 19-years sub-periods 1979–1997 and 1998–2016.

Apart from linear correlations and comparison between means, the main method used is the CI. The first step for the CI calculation is to sort the daily precipitation values in ascending order. Then the cumulative percentage of rainy days is plotted against the corresponding cumulative percentage of rainfall amounts. The plot has a markedly positive exponential shape. These exponential curves, also called standardized precipitation curves (Jolliffe and Hope 1996), specifically suggested by Riehl (1949) and Olascoaga (1950), are of this kind:

\[ y = axe^{bx} \tag{1} \]

where \( a \) and \( b \) are constants, that can be calculated by means of the least-squares procedure (Martin-Vide 2004):

\[
\ln a = \frac{\sum n_i \ln y_i + \sum n_i \ln x_i - \sum x_i \ln y_i - \sum x_i \ln n_i}{N \sum x_i^2 - (\sum x_i)^2} \tag{2}
\]

\[
b = \frac{N \sum x_i \ln y_i + \sum n_i \ln x_i - N \sum x_i \ln n_i - \sum x_i \ln y_i}{N \sum x_i^2 - (\sum x_i)^2} \tag{3}
\]

In Table 1, an example is developed.

The definite integral of the exponential curve between 0 and 100 is the area, \( S \), under the curve, and \( 5,000 - S \) is the area compressed by the curve, \( y = x \), and \( x = 100 \) (5,000 is the area of the triangle in which it is inserted), lets name \( S' \). Then CI is defined as (Martin-Vide 2004):

\[
CI = \frac{S'}{5000} \tag{4}
\]

The CI measures the relative separation of the exponential curve from the \( Y = X \) line. Note that the separation is greater (or CI is higher), when the weight of a few days, the rainiest ones, in the total is higher (Martin-Vide 2004; Cortesi et al. 2012; Benhamrouche et al. 2015). The value of the CI oscillates between 0 and 1 and it is similar to the well-known Gini index (Monjo and Martin-Vide 2016). Figure 1 shows the positive exponential curves of the two extreme CI cases (Fig. 2).

It is necessary to remember that the CI is very sensitive to the quality of data, as well as the longitude of classes. In general, the CI of meteorological station with no complete daily data should not be analyzed. On the other hand, calculating the CI from classes of, for example, 5 mm or 10 mm, instead 1 mm, produce a diminution of CI values (Benhamrouche and Martin-Vide 2018; Nery et al. 2017).

### Table 1: Frequency distribution in classes of 1 mm, where \( x_i \) is the accumulated relative frequencies in percentage, and \( y_i \) is the corresponding accumulated percentage of total precipitation, of Que Son meteorological station (1979–2016)

| Super limit class | Midpoint (\( m_i \)) | \( n_i \) | \( \sum n_i \) | \( \sum m_i \cdot n_i \) | \( \% \sum n_i = x_i \) | \( \% \sum m_i \cdot n_i = y_i \) |
|-------------------|----------------------|-----------|---------------|------------------------|------------------------|------------------------|
| 0.9               | 0.5                   | 202       | 202           | 101                    | 3.604568               | 0.100388               |
| 1.9               | 1.5                   | 1490      | 1692          | 2274.187               | 2375.187               | 30.19272               | 2.360793               |
| 2.9               | 2.5                   | 415       | 2107          | 1037.5                 | 3412.687               | 37.59814               | 3.392006               |
| 3.9               | 3.5                   | 289       | 2396          | 1012.28                | 4424.967               | 42.75517               | 4.398152               |
| 4.9               | 4.5                   | 224       | 2620          | 1014.16                | 5439.127               | 46.75232               | 5.406166               |
| 5.9               | 5.5                   | 231       | 2851          | 1270.5                 | 6709.627               | 50.87438               | 6.668967               |
| 6.9               | 6.5                   | 176       | 3027          | 1144.686               | 7854.314               | 54.01499               | 7.806716               |
| 7.9               | 7.5                   | 161       | 3188          | 1212.121               | 9066.434               | 56.88794               | 9.011491               |
| 8.9               | 8.5                   | 127       | 3315          | 1079.5                 | 10,145.93              | 59.15418               | 10.84458               |
| 9.9               | 9.5                   | 120       | 3435          | 1140                   | 11,285.93              | 61.2955                | 11.21754               |
| 10.9              | 10.5                  | 164       | 3599         | 1726.904               | 13,012.84              | 64.22198               | 12.93398               |
| 11.9              | 11.5                  | 88        | 3687         | 1012                   | 14,024.84              | 65.79229               | 13.93985               |
| 12.9              | 12.5                  | 104       | 3791         | 1300.655               | 15,325.49              | 67.64811               | 15.23262               |
| 13.9              | 13.5                  | 95        | 3886         | 1285.455               | 16,610.95              | 69.34333               | 16.51028               |
| 352.9             | 352.5                 | 1         | 5600         | 352.5                  | 98,862.67              | 99.92862               | 98.26356               |
| 395.9             | 395.5                 | 1         | 5601         | 395.5                  | 99,258.17              | 99.94647               | 98.65666               |
| 411.9             | 411.5                 | 1         | 5602         | 411.5                  | 99,669.67              | 99.96431               | 99.06567               |
| 467.9             | 467.5                 | 1         | 5603         | 467.5                  | 100,137.2              | 99.98216               | 99.53034               |
| 472.9             | 472.5                 | 1         | 5604         | 472.5                  | 100,609.7              | 100                    | 100                    |
Inverse Distance Weighting (IDW) interpolation was performed using 15 measurement points (stations) in ArcMap 10.5 to generate the spatial distribution of daily precipitation Concentration Index over the study area for the periods 1979–1997, 1998–2016, and 1979–2016.

3 Dataset and study area

The data used are the daily precipitation amounts recorded from 1979 to 2016 (38 years) in 15 meteorological stations located in the Da Nang city and Quang Nam province in Central Coast Vietnam (Table 2). These stations belong to the Vietnamese National Center for Hydro-meteorological Forecasting (NCHMF).

Data quality control has been carried out by the National Center for Hydro-meteorological Forecasting (NCHMF), Vietnam (Fig. 3).

The quite similar CI values obtained are also a guarantee of its quality.

The study area is located on the coast of the central Vietnam, between parallels 15° N and a bit more than 16° Nin front of the South China Sea. The climate is predominantly tropical of monsoon, Am Köppen’s type, although in the highlands farthest from the sea is temperate.
temperatures are high; between 20 and 30 °C all the monthly averages at sea level. The precipitation is abundant, usually of about or above 2,000 mm. The annual regime shows a maximum in October, with about 600 mm (rainy season: from September to December), and a minimum in March, with less than 30 mm (dry season: from February to April). The mean annual relative humidity is over 80%. It is important to highlight the high sea surface temperatures, close to 30°C during the hottest months.

The study area covers 11,700 km² (1,260 km² belongs to Da Nang city and 10,440 km² to Quang Nam province) and has more than 2.1 million people (about 180 inhabitants per square km). The new crops and settlements, and in general the increasing land uses, are sensitive to precipitation concentration.

### 4 Results

CI values for the 15 stations in the period 1979–2016 are presented in Table 3. They range from 0.62 (in Hien station) to 0.72 (the highest value, in Da Nang, the lowest and closest to the East sea). The mean value of the 15 stations is 0.68, which is considered a high value.

The spatial pattern of the CI values (Fig. 4) shows increasing values from west to east as from the mountain to

| Name         | Long E | Lat N | Elevation (m a.s.l) |
|--------------|--------|-------|---------------------|
| Ai Nghia     | 108.104| 15.874| 16                  |
| Cam Le       | 108.206| 16.013| 11                  |
| Cau Lau      | 108.279| 15.860| 2                   |
| Da Nang      | 108.207| 16.045| 4.75                |
| Giao Thuy    | 108.127| 15.839| 9                   |
| Hien         | 107.646| 15.917| 490                 |
| Hiep Duc     | 108.102| 15.578| 22                  |
| Hoa An       | 108.365| 15.87  | 9                   |
| Hoi Khanh    | 107.919| 15.827| 44                  |
| Kham Duc     | 107.79 | 15.427| 396                 |
| Que Son      | 108.1   | 15.7   | 19                  |
| Nong Son     | 108.033| 15.7   | 27                  |
| Thanh My     | 107.833| 15.767| 25                  |
| Tien Phuoc   | 108.3   | 15.483| 55                  |
| Tra My       | 108.233| 15.35  | 123.11              |

Fig. 3 Location of the 15 meteorological stations used in this study
the sea. This is evidenced by a statistical positive significant correlation between eastern longitude and CI: $R = +0.65$, $p < 0.01$ (Fig. 3). Conversely, there is no correlation between latitude and CI (Figs. 5, 6). The lowland has the high CI values, so there is a statistical negative significant correlation between altitude and CI: $R = -0.60$, $p < 0.01$ (Fig. 4).

The two 19-years sub-periods, i.e., 1979–1997 and 1998–2016 have been considered in order to detect any significant trend (Figs. 7, 8, and 9). Eleven out of 15 stations increased the CI value from the first sub-period to the second one, and the mean value went from 0.666 to 0.682, that constitutes a non-negligible change.

## 5 Discussion

The CI proposed by Martin-Vide (2004) has been used in many countries to evaluate the pluviometric weight of the rainiest days in the total amount, i.e., the concentration of

| Station     | CI value | Station     | CI value |
|-------------|----------|-------------|----------|
| Da Nang     | 0.72     | Hien        | 0.62     |
| Cam Le      | 0.70     | Thanh My    | 0.67     |
| Hoi An      | 0.70     | Nong Son    | 0.66     |
| Cau Lau     | 0.70     | Que Son     | 0.67     |
| Giao Thuy   | 0.67     | Hiep Duc    | 0.67     |
| Ai Nghia    | 0.69     | Tien Phuoc  | 0.65     |
| Hoi Khanh   | 0.67     | Kham Duc    | 0.67     |
| Tra My      | 0.69     |             |          |
a high percentage of precipitation amount in a few very rainy days. It is also an index that can give us a better picture about erosivity or aggressiveness of precipitation and its effects on soil erosion than the usual indices based on monthly precipitation (Bessaklia et al. 2018), such as the monthly precipitation concentration index developed by Oliver (1980) and the modified Fournier Index developed by Arnoldus (1980). This is an important subject in many countries because erosion reduces soil fertility, modifies the conditions for crops, alters agricultural practices and causes the rapid clogging of reservoirs (Scholz et al. 2008; Ibisate et al. 2016). There are two country groups more affected by soil erosion: very arid countries with poor vegetation cover and countries with high precipitation. Vietnam belongs to the second group, so it is interesting to evaluate the daily precipitation concentration.

The values obtained for Central Coast Vietnam (Da Nang and Quang Nam) between 0.62 and 0.72 can be considered high. As a reference, the threshold that separates high CI values from moderate ones is 0.61 (Martin-Vide 2004). The value of 0.61 means that 25% of the rainiest days account for approximately 70% of the total amount. CI values higher than 0.66 mean that 25% of the rainiest days represent at least approximately 75%, as occurs in most of the stations analyzed. The Vietnam CI values are not so high than the calculated for the Pearl River basin in China (Zhang et al. 2009), over 0.74, but higher in general terms than the obtained in central and north Europe (Cortesi et al. 2012), with oceanic and continental mid latitudes climates. The CI values for Vietnam are quite

Fig. 6 Linear correlation between altitude and CI for the 1979–2016 period

Fig. 7 Spatial distribution of CI values for the 1979–1997 sub-period
similar to the Mediterranean regions ones, as those of a large part of Spain (Martin-Vide 2004; Serrano-Notivoli et al. 2018), central Chile (Sarricolea et al. 2019), as well as some southern USA states (Texas, California) (Royé and Martin-Vide 2017) and other countries. This is consistent with the fact that subtropical and tropical regions have higher CI than the mid and high latitudes countries (Monjo and Martin-Vide 2016), although there is any exception such as northwest Puerto Rico with relatively low values (Vélez et al. 2018).

With respect to the most critical areas, in the study area the meteorological stations closer to the sea are those that have the highest CI values, as shown by the statistically significant correlation obtained between eastern longitude and CI, $R = +0.65$, $p < 0.01$. This is also true in the case of peninsular Spain in relation to the Mediterranean sea (Martin-Vide 2004; Serrano-Notivoli et al. 2018). Heavy rainfall during the humid monsoon period and other intense tropical showers (including the rain produced by typhoons) contributes to the high CI values of Vietnam. The sea humid air flows are particularly effective in coastal sectors, where the CI values are the highest.

Contrary to what happens in Vietnam in many of the studied regions the correlation between the number of rainy days and CI is negative and statistically significant, as for instance occur in the USA ($R = -0.25$, $p < 0.001$, using a grid with 13,527 cells) (Royé and Martin-Vide 2017), Europe ($R = -0.68$, $p < 0.01$, for 530 meteorological stations) (Cortesi et al. 2012) and other areas and countries. In general, higher the number of rainy days, lower the CI value. Nevertheless, for the whole planet, at a global scale, using the Gini index of daily precipitation, similar to the CI one, there are regions with a few rainy days with relatively low CI values, and the opposite as occurs in Vietnam (Monjo and Martin-Vide 2016).

Respect to the relationship between altitude and CI, in general the correlation is also negative and significant, in correspondence with what was obtained for Vietnam, $R = -0.60$, $p < 0.01$ ($R = -0.51$, $p < 0.001$, for the USA).

Several of the CI studies analyses the recent changes in CI. Most of them show predominant increasing trends, even significant ones, as is the case of Spain (Serrano-Notivoli et al. 2018), USA (Royé and Martin-Vide 2017), Mediterranean basin (Mathbou et al. 2019), etc. In Vietnam, the southern part of the country exhibits a dramatic increase in heavy rainfall events in the wet seasons (Ho-Hagemann et al. 2011) that could explain the increase of CI values obtained in the study area. For the years 2001–2050, based on the IPCC SRES A1B and A2 scenarios, heavy rainfall events
tend to remain unchanged or to decrease for all Vietnam subregions except R5, where the study area is located (Ho-Hagemann et al. 2011).

6 Conclusion

The values of Concentration Index (CI) of daily precipitation in Central Coast Vietnam are high, they range between 0.62 and 0.72. Over the study area, only 25% of the rainiest days account for more than 70% of annual total amount, even in most of the stations analyzed the mentioned 25% represent at least 75% of the total amount—in Da Nang it is approximately 80%.

Heavy rainfall during the humid monsoon period and other heavy tropical showers (including the rain produced by typhoons) are the most likely causes of the high CI values of Vietnam.

Locations closer to the sea have a highest CI values, as shown by the statistically significant correlation obtained between eastern longitude and CI. The lowest locations also have the highest CI values, as shown by the negative significant correlation obtained between altitude and CI.

In general terms, the CI has increased somewhat between the two 19-year sub-periods that make up the study period.

As a recommendation for future researchers in the scientific field of the concentration and intensity of precipitation, it would be highly recommended to use daily scales, as in the current article, and even sub-daily, to obtain the finest information about the temporal structure of precipitation. Under climate change, variations in CI, as well as other daily and sub-daily precipitation indices, are of great interest.

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Author contribution AB Conceptualization, writing—original draft, software, formal analysis, visualization. JMV and QBP formal analysis; writing—original draft, visualization. MEK and MCMG data curation, writing, review and editing. All authors reviewed the final manuscript.

Data availability The data that support the findings of this study are available from [Quoc Bao Pham, phambaoquoc@tdmu.edu.vn], upon reasonable request.
Daily precipitation concentration in Central Coast Vietnam

Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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