

**CHARACTERIZING TEMPORAL AND SPATIAL VARIABILITY OF
METEOROLOGICAL DROUGHT IN HANOI CITY, VIETNAM**

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Abstract: *For the last decades, Hanoi city (HN), Vietnam has suffered a series of super extreme meteorological droughts and resulting in tremendous socio-economic losses. This study analyzed the temporal and spatial variations of meteorological drought in HN from 1980 to 2014. Based on the standardized precipitation index (SPI) that was calculated from 24 precipitation monitoring stations, three time scales (month, year and decade) for the meteorological drought frequency (DF) and meteorological drought area were applied to estimate the spatio-temporal structure of meteorological droughts by employing ArcGis 10.3. A time-series analysis showed that winter droughts and spring droughts occurred frequently for almost half of the year from November to May. Summer droughts occasionally occurred in severe drought decades: the 1980s, 1990s and 2000s. During the period of observation, the percent of meteorological drought area in Hanoi city increased from the 1980s (<8%) to the 1990s (>13%). The highest drought area of 54% total areas was affected by drought in the hydrological year of 1992-1993, when the area experienced its most severe drought both in terms of area and severity.*

Key words: Drought characteristics, Meteorological drought, Hanoi City

1. INTRODUCTION

Drought is one of the most severe and least understood of all natural hazards, affecting on billions of people and ecosystems annually around the world. It can affect large areas and may have serious environmental, social and economic impacts (Hao & Singh, 2015; Hayes, 2002; Wang, He, Fang, & Liao, 2013).

Globally, about 22% of the economic damage caused by natural disasters and 25% of the damage in terms of the number of persons affected can be attributed to drought. These impacts depend on the severity, duration, and spatial extent of the precipitation deficit, as well as the socioeconomic and environmental vulnerability of affected regions (Hao & Singh, 2015; Mishra & Singh, 2011).

Avoiding meteorological drought is impossible as it is driven by many complicated factors and occurs very slowly and hardly to identify. However, assessing and monitoring meteorological droughts are normally performed based on drought indices. For the last century, various drought indices have been developed as summarized by (Dai, 2011, Mishra & Singh, 2010, 2011) in which the standardized precipitation index (SPI) is widely used across the world. The SPI for any location is calculated, based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero (McKee et al., 1993; Edwards and McKee, 1997).

In Vietnam, drought is one of the most frequent natural disasters, only after flood and

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storm, and has been becoming more severe due to impacts of annual El Niño (Lohmann & Lechtenfeld, 2015). Hang et al., 2013 reported that droughts mainly occur between November and March in all the sub-regions in different extents and locations across Vietnam. Drought has had many impacts on the local agriculture and livelihood (Lohmann & Lechtenfeld, 2015; M. T. Vu et al., 2015; T. H. Vu & Nguyen, 2010). In order to deal with the drought issues during the past years, the Vietnamese government has put a lot of efforts to develop drought management measures. However, the drought situation is still very complex and unpredictable, for instant in dry season between 2015 and 2016, Vietnam has experienced the historical drought in the period of 100 years, affecting on millions of people across the country, especially in the Central, South-Eastern and the Mekong delta together with serious seawater intrusion destroying agricultural crops and leading to fresh water shortage widely across these regions. Thus, in term of water resources management, natural disaster prevention and mitigation, understanding spatial-temporal variability of drought is essential in order to mitigate of impacts of drought on water resources systems and socio-economic losses (Jain et al., 2015). At present, there are few publications dealing with the drought characteristics in Vietnam in general and in Hanoi city in particular. This study focuses on analyzing spatial-temporal variations and trends of meteorological droughts in Hanoi city, Vietnam during 1980–2014.

2. MATERIALS AND METHODS

2.1. Materials

Daily near surface temperature and rainfall data of 24 meteorological stations during 1980–2014 in Hanoi and sub-regions were used to calculate SPI indices as shown in Figure 1.

2.2. Methods

The meteorological drought index (SPI) in Hanoi city was calculated based on the monthly precipitation data of 24 stations from center and sub-regions of Hanoi capital city in period of

1980–2014. The formula of SPI is described as:

$$SPI = (P - P_0) / \sigma \quad (1)$$

Where: P and P_0 are precipitation and average precipitation (mm) in a given time period, respectively, and σ is the standard deviation of precipitation. According to Eq. (1), SPI can quantify the degree of wetness in different time periods (e.g., 1 month, 3 months, 6 months, 1 year, 2 years, and and so on) depending on user application. The SPI value normally ranges from (–2.0) to (+2.0). A value of (+2.0) indicates extremely wet conditions; (1.5) to (1.99) indicates very wet; (1.0) to (1.49) moderately wet; (0.99) to (–0.99) near normal; (–1.0) to (–1.49) moderately dry; (–1.5) to (–1.99) severely dry; and an SPI value of (–2.0) or (less) indicates extremely dry conditions (McKee et al. 1993).

Additionally, the index of drought frequency (DF) is proposed to further analyze the spatial variations of meteorological droughts occurring in Hanoi city. The DF is calculated from statistics of meteorological drought events from 1980 to 2014 as followed: $DF = n/N * 100\%$ (2)

Where n is the number of years in which a meteorological drought occurred, N is number of years in the study. In this paper, N is 35 for the period 1980–2012.

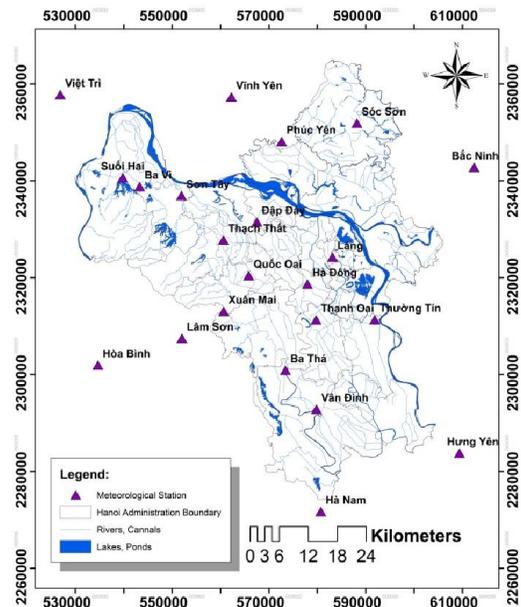


Figure 1. Location of meteorological stations in Hanoi city, Vietnam

The Drought Indices Calculator (DrinC) (Tigkas D.et.al, 2013) was used to calculate the SPI indices in different time scale such as monthly, annual SPI, SPI3, and SPI6. ArcGIS 10.3 ESRI was employed to generate spatial-temporal variability of meteorological drought in different timescale in Hanoi city.

3. RESULTS AND DISCUSSIONS

3.1. Spatial Distribution of Meteorological Drought

To investigate the spatial distribution variability of DF at different timescales, the monthly and annual time-scale variability of DF in HN were calculated and analyzed based on the above mentioned methods.

3.1.1 Monthly and Annual Variability of DF

The spatial distribution variability of DF of 12 months from 1980 to 2014 in HN is shown as Figure 2. DF showed a large variability in different months. Hanoi suffered from meteorological droughts in a large area for a period of half a year (January, February, March, April, May, October, September, and November). During spring and winter, most of the meteorological drought events were reported in the study area (Hang et.al., 2013). As shown in Figure 2, the central areas and southern portions are severely drought-afflicted areas. The monthly variability of DF also displayed a meteorological drought pattern over time. From February to May, most of the meteorological droughts ($DF > 25\%$) occurred in central and southern parts of the city. In June, the meteorological drought area rapidly narrowed. The area of $DF > 25\%$ was located in a limited extension of central and western parts. From June to September, the DF in the study area was low with a slightly increase. The distribution of meteorological droughts was spread from east to west and from the east

to the south. In September, meteorological droughts began to occur again in a large area, when $DF > 25\%$ and $DF > 20\%$ were detected in eastern and southwestern HN city, respectively. The meteorological drought area increased rapidly from October. It is clearly found that one fourth of study area is at a high drought risk. The DF of the entire central parts of HN city is greater than 25%. Except for the limited extension of the central portion, the DF of most central city exceeded 25% in February, meaning that these regions suffered droughts biyearly.

Surprisingly, meteorological drought frequency in HN city occurs significantly into two paths: at the beginning, meteorological drought occurs in the eastern parts then moving to the center city and expanding to the western parts between September to December while from February to May, meteorological drought occurs frequently from eastern parts moving to center and spreading to southern parts. These trends can be attributed to various changes of hot-cold atmospheric flows from the East Sea and from South China as well as impacts of heat island phenomenon in HN capital city.

As shown in Figure 3, the annual droughts DF (1980-2014) were scattered, in contrast to the monthly scale. More than 36% of the area in SC had a relatively high DF that exceeded 25%, meaning that all of SC has been a region of high drought risk for more than half century. An area with high meteorological drought frequency was identified in the western mountains and eastern plains. In contrast, central part of Son Tay, Thach that, Quoc Oai, Thuong Tin, Phu Xuyen, which occupies a large portion of the study area with relatively flat and fertile grounds, suffered fewer droughts events.

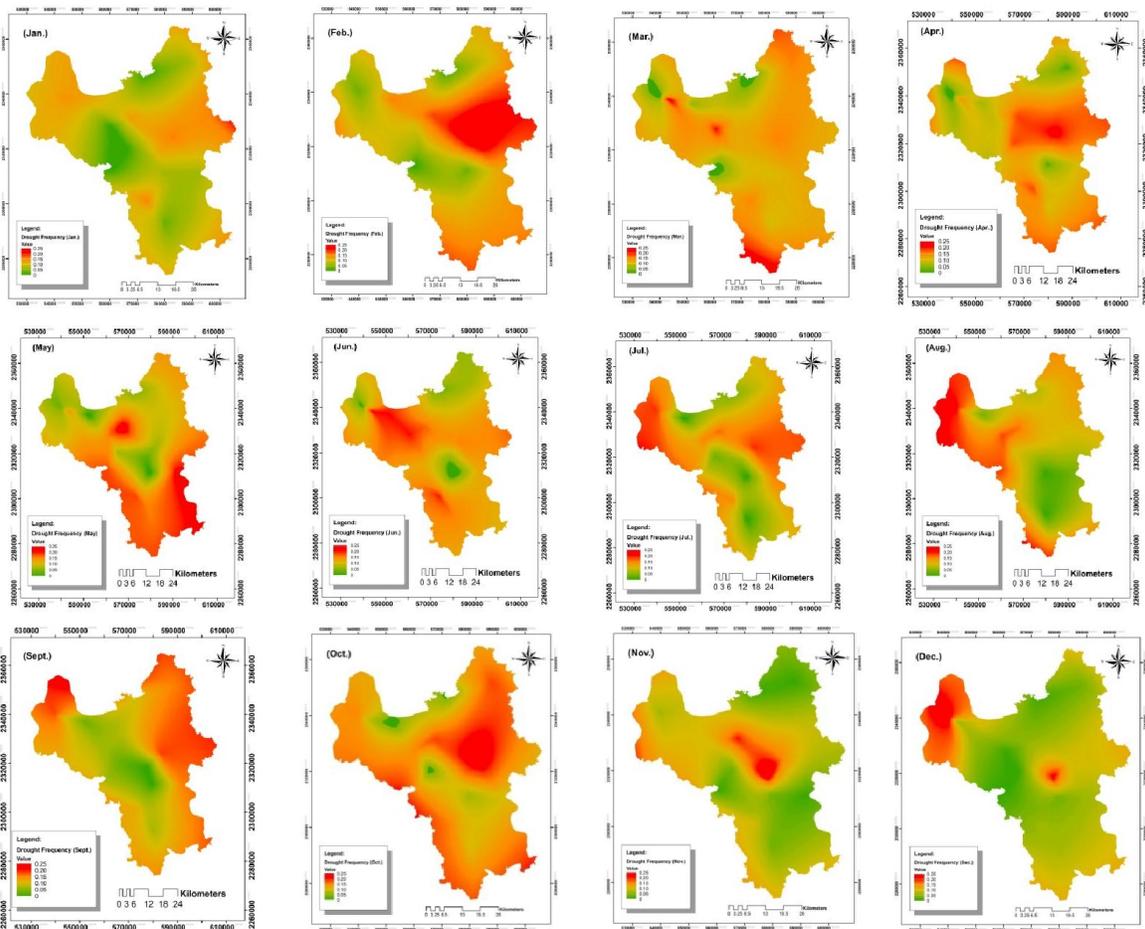


Figure 2. Spatial distribution of the monthly DF in HN from 1980 to 2014.

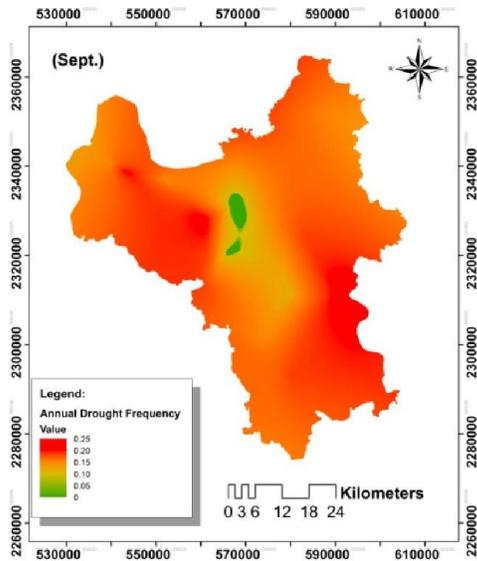


Figure 3. Spatial distribution of annual DF in HN from 1980 to 2014.

3.1.2 Decade Time Scale Variations of the Meteorological Drought Severity Distribution

Decade variations in meteorological drought severity distribution were also examined by dividing the study period into four 10-year sub-periods (1981–1990, 1991–2000, 2001–210). The annual meteorological drought severity as estimated by the meteorological drought level was calculated based on SPI index. For the other meteorological drought severity levels, such as severe drought or extreme drought, which were not inevitable, we only plotted the spatial distribution of DF of mild meteorological drought severity for three-decade periods (Figure 4). During the 1980s, most of HN suffered from mild meteorological droughts with a DF greater than 20% (Figure 4a). Whereas, meteorological droughts that were worse than moderate in nature did not occurred.

Moderate meteorological droughts sporadically occurred in limited areas in My Duc and Ung Hoa districts. In the 1990s, the mild meteorological drought area narrowed down rapidly (Figure 4b), which just occurred in northeastern and northwestern area. However, severe meteorological droughts were detected at the junction of Soc Son and Me Linh districts. In the 2000s, the meteorological droughts aggravated. Mild meteorological droughts spread to the eastern and western parts of HN (Figure 4c). In addition to the severe meteorological droughts that occurred in some portions of Ba Vi, Son Tay, Thach That, Quoc Oai and Hoang Mai, extreme meteorological droughts were detected at the junction of Ba Vi and Quoc Oai districts, which was the severe drought area in the 2000s.

3.2. Variability of Meteorological Drought Areas

The meteorological droughts area is an important index for the estimation of meteorological drought magnitude. We evaluated the variations in meteorological droughts area of three time scales: decade, year and month. Figure 5 shows the decade variations in meteorological drought area from

the 1980s. Similar to the result in Section 3.1.2, there is an abnormal decrease in the 1990s. The meteorological drought area in HN increased overall from less than 8% to more than 13%, indicating that the meteorological droughts of HN rapidly aggravated over 10 years, which may be caused by global change and human activities.

Figure 6 shows the monthly drought area variability over three decades. Region-wide droughts were not unusual from July to December, with a drought area percentage of greater than 30% in all five of the study periods. The values exceeded 40% in two severe droughts periods of the 1980s and 1990s, indicating that winter drought were common in HN. The meteorological drought area percentage decreased rapidly from April and reached the minimum drought in May, which is the rainy period. Although the drought area increased from May, there was a wide variation in the three decades. For the 1980s, the 1990s and the 2000s, widespread droughts occurred in July, September and December, with high drought area percent of 40%, 30% and 40%, respectively. Occasional summer droughts also need to be noted.

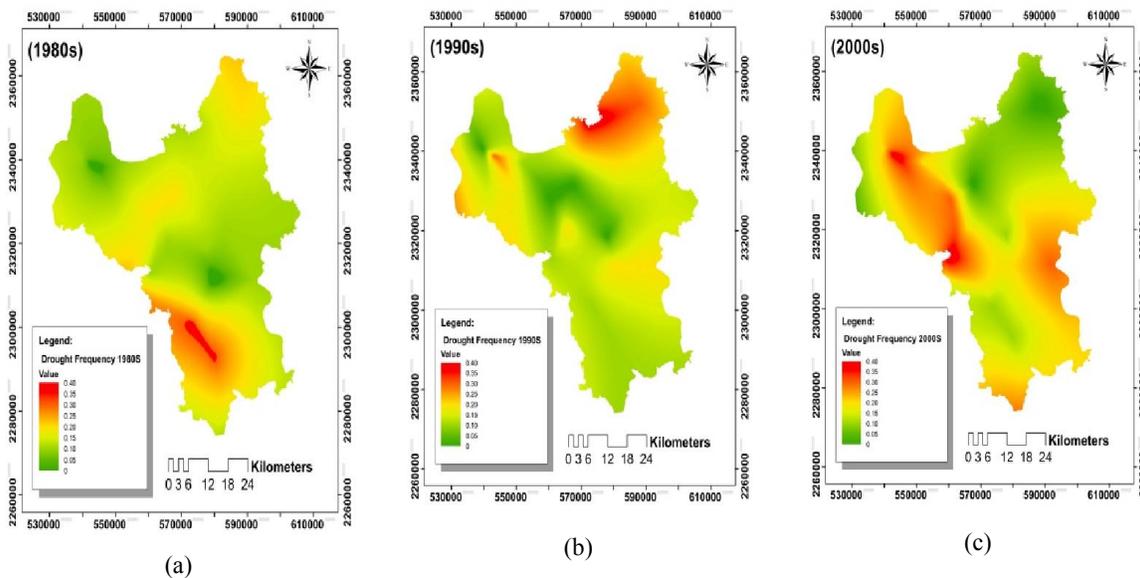


Figure 4. Decadal spatial distribution of DF of mild meteorological drought severity from 1980 to 2014. (a) 1980s; (b) 1990s; (c) 2000s.

An annual analysis detailed the variability in meteorological drought area (Figure 7). Except for the highest value of 54% in 1992-1993, when a severe meteorological drought occurred that last for 85 days, the meteorological drought area percentage remain steadily low during the 1990s and the 2000s. From the 2000 to 2014, several high values appeared, such as 25% in 2002-2004, 33% in 2006-2007, 15% in 2011-2012 and 25% in 2014-2015. These results indicate the meteorological droughts have changed variously in recent years.

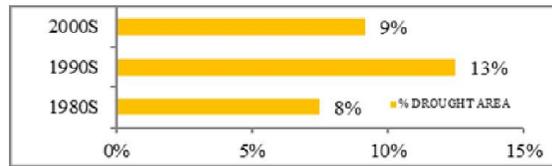


Figure 5. Decade meteorological drought area percentage.

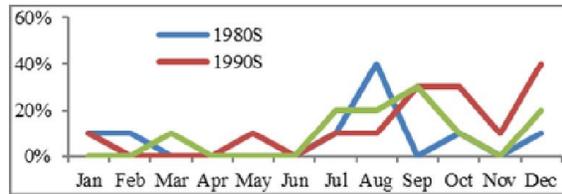


Figure 6. Monthly meteorological drought area percentage over three decades.

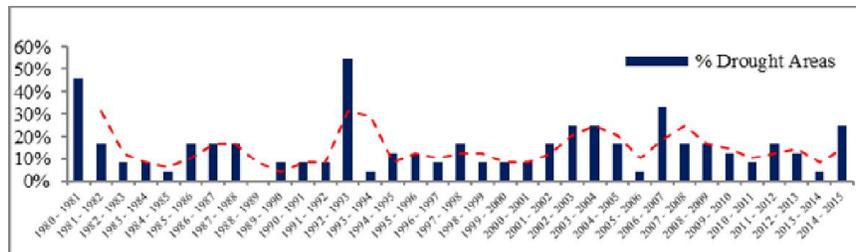


Figure 7. Annual meteorological drought area percentage.

4. CONCLUSIONS

The present study explored the regional meteorological drought frequency and meteorological drought area analysis in HN from 1980 to 2014 considering the spatio-temporal structure of meteorological droughts. The meteorological drought tendency, affected area and severity and joint distributions were constructed at monthly, annual and decade time scales. The simple SPI approach was utilized to capture different time scales of meteorological droughts in HN.

This analysis result demonstrated that meteorological droughts occurred commonly in the 1980s. Winter droughts and spring droughts occurred from November to March and were not peculiar, with more than 25% of the area suffering meteorological droughts. In contrast, summer droughts occasionally occurred during severe drought periods with a less temporal pattern, which can be an indicator of

meteorological drought severity. The decade meteorological drought analysis showed that meteorological drought in HN increased especially in the 1990s. The frequency and intensity of meteorological drought became the most frequent and strongest in the 1990s with a meteorological drought area of 54%. The spatial analysis showed that whole HN is at meteorological drought risk except for the central parts of Thanh Oai, Quoc Oai, Phuc Tho districts. These results indicate that gridded precipitation data can further the application of SPI in the estimation of the spatial distribution of meteorological drought. This study has analyzed the characteristics of regional meteorological droughts in HN. However, further research on temporal and spatial variability of meteorological droughts in HN is still warranted. Research on revealing the deterministic mechanism of meteorological droughts in HN is currently underway.

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Tóm tắt:

PHÂN TÍCH ĐÁNH GIÁ HẠN KHÍ TƯỢNG THEO KHÔNG GIAN VÀ THỜI GIAN KHU VỰC THÀNH PHỐ HÀ NỘI, VIỆT NAM

Hạn hán tại khu vực Đồng bằng sông Hồng nói chung và khu vực Tp Hà Nội nói riêng diễn ra rất phức tạp, ảnh hưởng rất lớn đến đời sống và sản xuất trong khu vực. Nghiên cứu này trình bày phương pháp và kết quả phân tích sự thay đổi các đặc trưng hạn khí tượng dựa trên chỉ số SPI tại khu vực Hà Nội từ năm 1980 đến 2014. Chỉ số SPI được tính toán dựa vào số liệu của 24 trạm khí tượng tại khu vực Hà Nội. Kết quả phân tích chỉ ra rằng hạn hán diễn ra thường xuyên vào mùa xuân và mùa đông từ tháng 10 đến tháng 5. Hạn hán vào mùa hè xảy ra thường xuyên theo chu kỳ 10 năm ở các thập niên 1980, 1990 và 2000. Trong giai đoạn 35 năm trở lại đây, tỷ lệ diện tích hạn hán tăng từ < 8% thập niên 1980 tới (>13%) trong thập niên 1990. Năm hạn hán xảy ra nghiêm trọng nhất tại khu vực Tp Hà Nội là năm 1992-1993 với trên 54% diện tích sản xuất khu vực này bị ảnh hưởng.

Từ khóa: Đặc trưng hạn hán, hạn khí tượng, Tp Hà Nội

BBT nhận bài: 03/9/2016

Phản biện xong: 10/10/2016