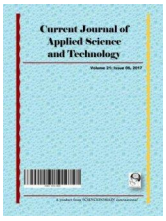

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Relationship between Drought and Rainfall Due to Tropical Cyclone and Depression in Ninh Thuan, Vietnam

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Authors' contributions

This work was carried out in collaboration between all authors. Authors PTPT and PMT designed the study, performed the statistical analysis, wrote the first draft of the manuscript. Author NMG provided the data. Authors HDD and BHL contribute to manage the study. All authors read and approved the final manuscript.

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ABSTRACT

Tropical depressions/cyclones are natural phenomena which might impact negatively on human beings and the environment. Like other natural hazards, they sometimes can cause severe damage to the economy, infrastructure and community so that the benefits that come along with such hazards have almost been neglected. On the land, rainfall during and after the tropical cyclones has significantly decreased drought conditions in some semi-arid and arid areas. In the case of Ninh Thuan Province, tropical depression/cyclones could cause the flooding in the area where it is passed, but the weak tropical depression/cyclones can help to increase 0.5 - 12.39

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times of monthly rainfall and contribute to total rainfall of 7 – 40% in dry season; and 0.4-2.18 times and 37 - 145% in wet season, respectively; or 3 – 39% of annual climatological rainfall. As the results, agriculture economic and local people can be taken a benefit from tropical depression/cyclones. Based on these results, the authorities can have some strategies to adapt and develop the local economy after such natural hazards.

Keywords: Tropical cyclone; tropical depression; rainfall; drought; SPI (standard precipitation index).

1. INTRODUCTION

Tropical depression (TD) and tropical cyclone (TC), also called typhoon, hurricane, are one of the most destructively and deadly natural disasters over the world due to the damage caused to the economy, society and ecosystems where they pass. Typically, hurricane Katrina (on 29 Aug 2005) was the costliest hurricane in US history, with total damage around $125 billion and 1,833 people died [1,2]. In 2013, the deadliest and costliest TC Haiyan struck the Philippines on November 8 and caused devastating damage estimated around $776 million and 6,245 people died, 28,626 injured and 1,039 missing [3]. In Vietnam, Damrey (early November 2017) has been the strongest TC hitting to South-Central Vietnam since 2001 (estimated the total damage reached over $1 billion, 107 dead, 315 wounds and 16 missing) [4]. Even though TD/TC has caused human and economic losses, it may be beneficial when it can bring rainfall to contribute to water budget in most the regions. Therefore, there are so many researches on the contribution of TC on total rainfall at different regions/places over the world such as in Australia [5,6], the Philippines [7], China [8,9], the Western North Pacific [10] and so on. However, there is limited conducts about the impact of TC-induced rainfall on drought. Lam et al showed that TC has accounted for 30% of the annual precipitation in Hong Kong and TC Viola which occurred in May 1964 broke the worst drought in 1963 [11]. In the eastern United States, Kam et al. [12] found that TCs contributed to total rainfall about 6% during 1980-2007 and 15% during storm season for active TC years and found an important role of TC-induced rainfall in the alleviation and removal of drought for some years. Another research from Kellner et al. [13] showed that rainfall from the landfalling tropical system was about 20% monthly rainfall in the storm season across the eastern U.S. Corn Belt during 1981-2012. Although the amount of such rainfall from TD/TC could not be the main source for water budget for these regions, it could play an important role to shorten drought duration and weaken drought intensity, to make late drought initiation and early drought recovery, and an overall reduction in the spatial extent of drought [12].

Ninh Thuan is one of the most arid provinces with the lowest rainfall (at Phan Rang station) in Vietnam. It recently experienced the worst and prolonged drought during 2015-2016 when the local government in the first time declared a state of emergency of drought all over the province in June 2015 and declared a natural disaster due to drought in some regions from Mar 2016 [14]. Ninh Thuan is less affected by TC/TD, just around one TC/TD event per year and sometimes it can cause heavy rain and drive floods with harmful impacts on crop production and livelihoods. However, considering on the other side, rain from TC/TD can contribute significantly to the water budget for this savanna region. Therefore, the goal of this paper is to research the relationship between meteorological drought condition and rainfall from TC/TD to understand the role of TC/TD in drought area in Ninh Thuan province during 2010 – 2015.

2. MATERIALS AND METHODOLOGY

2.1 Study Area

Ninh Thuan is located in the southern part of Vietnam Central Coastal region, with coordinates of 11°45′N, 108°50′E (Fig. 1). This province has the highest temperature with the annual average temperature of 26 – 27^{o}C and the lowest average rainfall in Vietnam with annual average rainfall about 700-800 mm in Phan Rang and gradually increasing to more than 1,100mm in mountainous areas. It has a typically tropical savanna climate in Phan Rang with the features of drought, heat, much wind and strong evaporation. There are two seasons: wet season (from September to November) and dry season (from December to August next year) [http://www.ninhthuan.gov.vn/english/Pages/Natural-conditions.aspx]. Ninh Thuan is less affected by TC/TD, just around one TC/TD event per year. It often occurs between September and

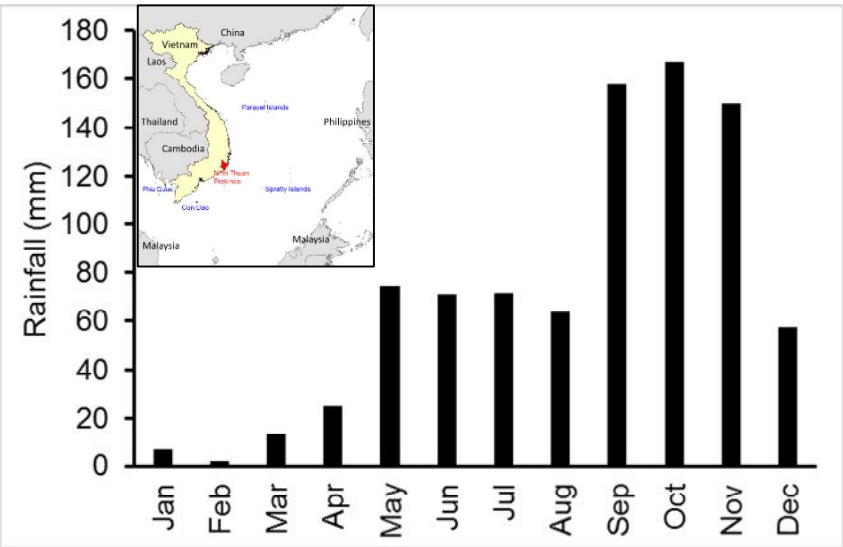

Fig. 1. Study area and mean rainfall at Phan Rang station, Ninh Thuan province during 1977-2015

November and causes heavy rain [15]. Generally, heavy rains are caused by some types of synoptic weather situations such as TC/TD, the Inter Tropical Convergence Zone (ITCZ), cold surge, NE monsoon, SW monsoon, low trough or the interactions between these factors.

2.2 Materials and Data

To study the impact of rainfall from TC/TD on drought condition, information of TC/TD in the period of 2010 – 2015 was collected at the website of Vietnam Center of Hydro-Meteorological Data (http://cmh.com.vn/). For rainfall, some daily data during TC/TD event from 2010 to 2015 and monthly data from 1977 to 2015 was observed at Phan Rang Hydro-Meteorological Station (Ninh Thuan province) and provided by South-Central Regional Hydrometeorological Center.

2.3 Data Analysis

For monitoring drought condition, Standardized Precipitation Index (SPI) [16] was calculated, following McKee et al. [17] with the updating from Guttman [18] and Hayes et al. [16,19]. The input of monthly rainfall data from 1977 to 2015 was used to calculate SPI by the SPI program at the website of National Drought Mitigation Center, University of Nebraska-Lincoln (http://drought.unl.edu/droughtmonitoring/SPI/SPIProgram.aspx). SPI-3 was mainly used for meteorological drought condition. In addition, SPI-3 Sep-Nov (SPI-wet) and SPI-9 Dec-Aug (SPI-dry) were calculated for seasonal variation and SPI-12 was assessed for annual variation. The classification of SPI for drought condition by Guttman [18] is in Table 1.

Table 1. Classification of dry and humid period in the function of the SPI [17]

SPI	Classification
≥ 2.00	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Almost normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
≤ -2.00	Extremely dry

3. RESULTS AND DISCUSSION

The variation of SPI-3 and SPI-12 at Phan Rang station during 1977-2015 are presented in Fig. 2. For a long timescale with the annual variation, extremely dry was found in 2004 and 2014 whereas extremely wet was in 2010 (Fig. 2a). In detail, Fig. 2b showed that SPI-3 did not fluctuate too much prior to 2010 while it decreased rapidly after that. Therefore, this region was in the moderately dry condition in most of the years, but it experienced severely to extremely dry in the years of 1977, 1979, 1986, 2003-2005, 2008, 2014-2015. The prolonged severe drought during 2003-2005 and 2014-2015-2016 were recorded

as two worst droughts in this region [20]. In contrast, there were some times that Phan Rang was in extremely wet condition (1980, 1990, 2009, 2010 and 2012. Generally, SPI-3 is more useful for meteorological drought monitoring and SPI-12 is good to applied for agriculture due to the precipitation deficit estimation in the next year.

For monitoring drought condition in dry and wet season, SPI-3 Sep-Nov and SPI-9 Dec-Aug were calculated (Fig. 3a and 3b). In the dry season, Phan Rang experienced the moderately dry condition in 1988 and 2014, severely dry in 2003 and 2008 and extremely dry in 2005. In the wet season, moderately dry condition was in 1982, 1983, 2001, 2002 and 2006 and severely dry was in 1997, 2004 and 2014. These results coincided with the prolonged severe drought during 2003-2005 and 2014-2015 in this region [20].

Generally, rain and heavy rains mainly support local water budget. In this area, rain and heavy rain are caused by some types of synoptic weather situations such as TC/TD, the Inter Tropical Convergence Zone (ITCZ), cold surge, NE monsoon, SW monsoon, low trough or the interactions between these factors. Therefore, rain from TD/TC or the interaction between TC/TD and the others factors partly affects water resource as well as dry condition in this region. The mean climatological annual rainfall at Phan Rang station during 1977 – 2015 is at 860.6mm (rainy season: 475.2mm and dry season: 385.4mm). During 2010 – 2015, there were 4 TCs and 4 TDs affecting indirectly and directly to Phan Rang, Ninh Thuan province (Table 2).

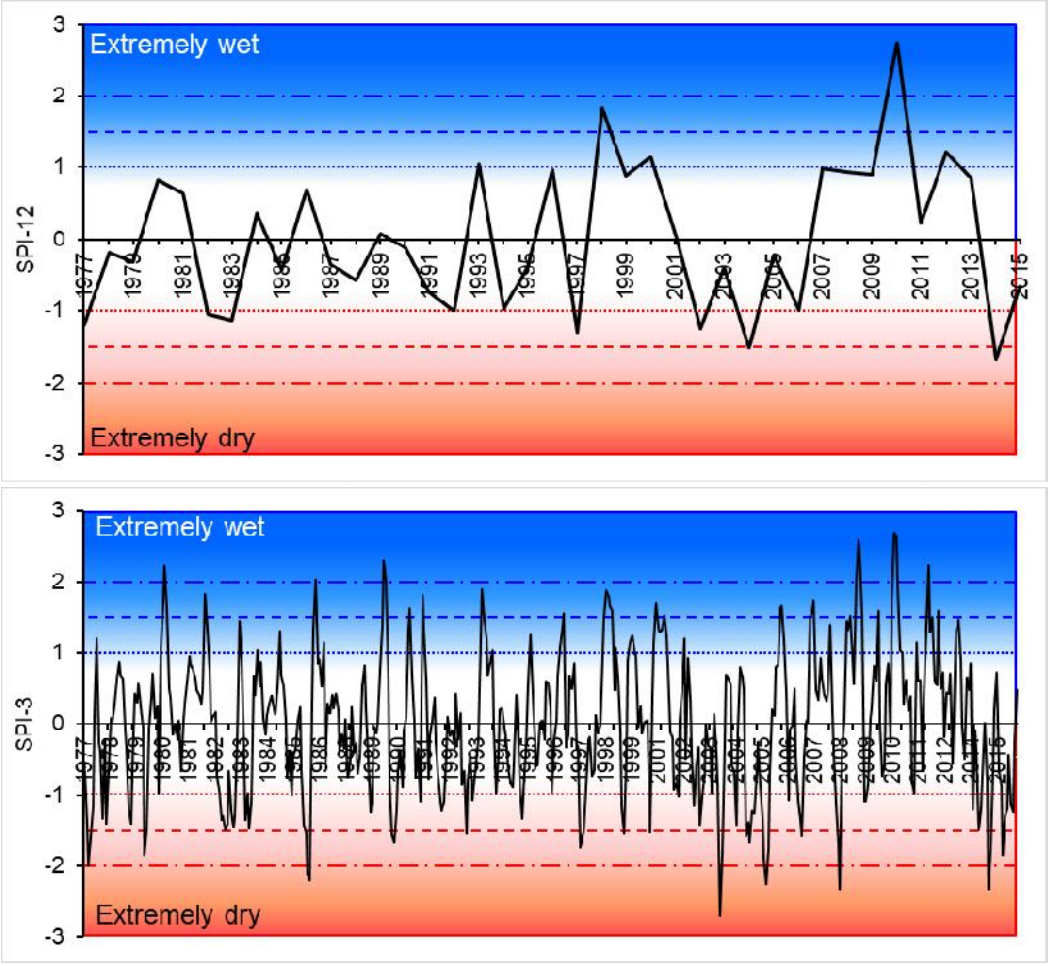

Fig. 2. Variation of annual SPI-12 (a: above) and SPI-3 (b: below) at Phan Rang station, Ninh Thuan province, Vietnam during 1977-2015 (Dot line: Moderately level; Dash line: Severely level; Round dot line: Extremely level)

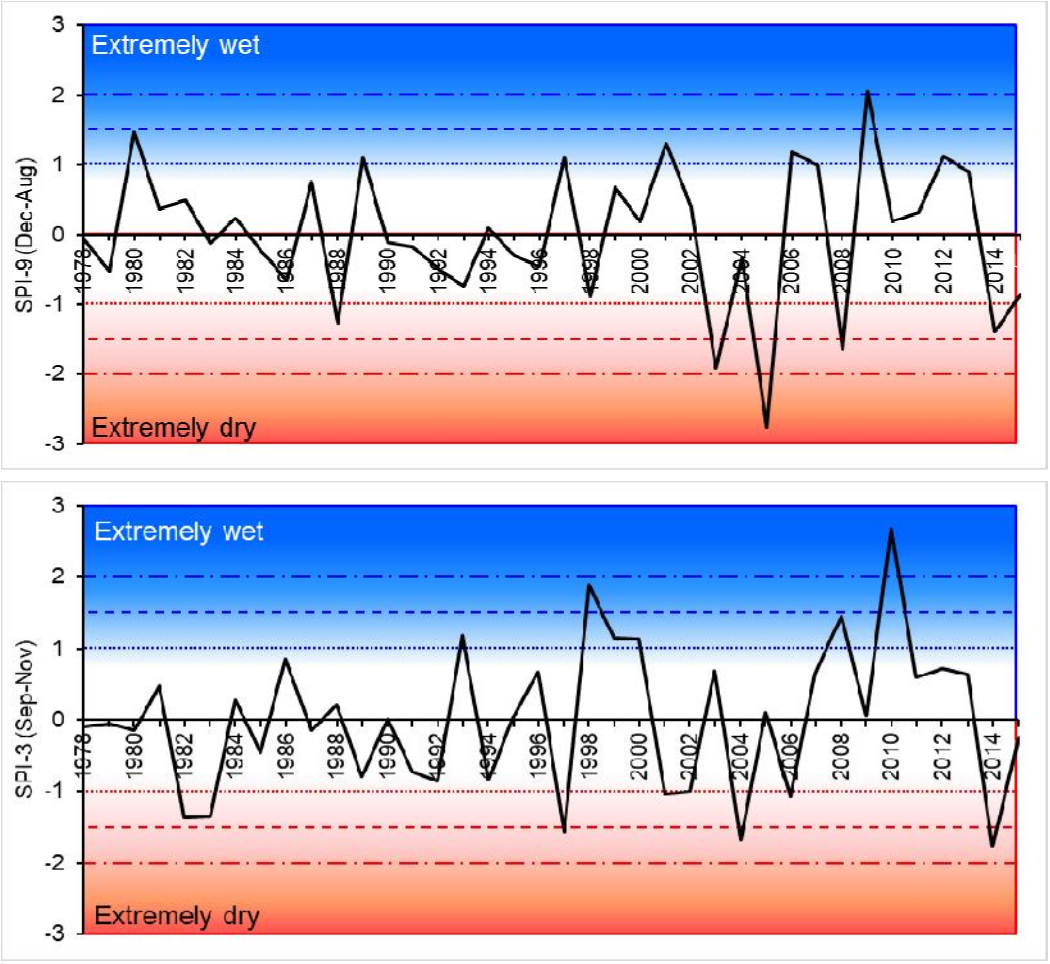

Fig. 3. Variation of dry SPI-9 (a: above) and rainy SPI-3 (b: below) at Phan Rang station, Ninh Thuan province, Vietnam during 1977-2015 (Dot line: Moderately level; Dash line: Severely level; Round dot line: Extremely level)

Table 2. Information of tropical cyclone and tropical depression in Ninh Thuan province in 2010-2015

Year	TC/TD	Rain dates	Rainfall of TD/TC (mm)	Rainfall in TD/TC month event (mm)	MCMR (mm)	ROR (times)	Notes
2010	TD 01VN	18-20 Jan	83.0	83.0	6.7 (Jan)	12.39	DS
	TD 07VN	29 Oct-04 Nov	690.0	545.0 (Oct) 516.6 (Nov)	167.1 (Oct) 150.0 (Nov)	2.18	RS
2011	-	-	-	-	-	-	
2012	TC Pakhar	01 Apr	156.0	160.2	24.8 (Apr)	6.29	DS
	TD 02VN	14-15 Nov	174.0	181.3	150.0 (Nov)	1.16	RS
2013	TC Sonamu	07 Jan	25.1	29.0	6.7 (Jan)	3.75	DS
	TD 05VN	06-07 Nov	120.0	330.9	150.0 (Nov)	0.80	RS
	TC Podul	15 Nov	59.5	330.9	150.0 (Nov)	0.40	RS
2014	TC Hagupit	12-13 Dec	28.8	95.8	57.5 (Dec)	0.50	DS
2015	-	-	-	-	-	-	

Notes: Rainfall of TD/TC: sum of rainfall during these TC/TD events, MCMR: mean climatological monthly rainfall in the period of 1977 – 2015 at Phan Rang station; ROR: ratio of rainfall from TC/TD over MCMR; DS: Dry season and RS: Rainy season)

Table 3. Contribution of tropical cyclone and tropical depression to the rainfall in Ninh Thuan Province

Year	TD/TC rainfall in Sep-Nov (mm)	% Mean rainfall in Sep-Nov	TD/TC rainfall in Dec-Aug (mm)	% Mean rainfall in Dec-Aug	Total TD/TC rainfall (mm)	Yearly rainfall (mm)	% total rainfall in year	% annual climatological rainfall
2010	690.0	145	83.0	22	773.0	1631.7	47	90
2011	-	-	-	-	0	894.3		0
2012	174.0	37	156.0	40	330.0	1147.5	29	38
2013	179.5	38	25.1	7	204.6	1048.6	20	24
2014			28.8	7	28.8	513.3	6	3
2015	-	-	-	-	0	699.7	0	0

In dry season, TD 01VN caused a rainfall accumulation up to 83.0 mm in 3 days (18-20 Jan 2010) (Table 2). The amount of rainfall from the abnormal TD in dry season was more than 12 times when compared to mean climatological monthly rainfall in January (6.7mm) (Table 2). It contributed about 22% of total rainfall in the dry season (Table 3). In 2012, the circulation of TC Pakhar integrated with cold surge caused an unusually heavy rain of 156.0mm on Apr 01. The amount of rainfall was more than about 6.3 times higher than mean rainfall in April and it accounted for 40% precipitation in dry season. Similarly, impacted by the circulation of TC Sonamu in Jan 2013 combining with cold surge, there was unusual rainfall on Jan 7 (25.1mm), which made the total rainfall in this month increase to 29.0mm, much higher than the monthly climatological rainfall in January during 1977-2015 at Phan Rang station. This rainfall amount contributed to 7.0% of rainfall in dry season. In 2014, TC Hagupit impacted indirectly to Ninh Thuan province on Dec 12 with small rainfall of 28.8mm, contributing to 30.0% of total rainfall in this month in 2014 (95.8mm) and 50.0% of monthly climatological rainfall in December (57.5mm) over 39 years at Phan Rang station. It supported 7% of rainfall in dry season. Therefore, rainfall due to TD/TC contributed 7% – 40% of precipitation in dry season in Phan Rang.

In wet season, from Oct 29 to Nov 04 2010, affected by an interaction between the circulation of TD 07VN and strong northeast monsoon and disturbances of easterly wind, an extremely heavy rain (690.0mm) was recorded at Phan Rang station. It was 1.45 times higher than precipitation in the rainy season. During 14-15 Nov 2012, TD 02VN combining with strong northeast monsoon and easterly wind disturbances caused 174.0mm rainfall, higher than mean monthly rainfall in November (150.0mm) (Table 2) and it was 37% of total rainfall in the rainy season (Table 3). In 2013, TD Wilma made landfall near Phan Rang on Nov 6 and TC Podul occurred on mid-Nov. On Nov 6, a weak but long-lived TD 05VN (TD Wilma or TD 30W) made landfall near Phan Rang, Ninh Thuan and rainfall recorded on early November was 120.0 mm. In addition, although TC Podul quickly weakened into a TD after striking the southern part of Vietnam Central Coastal region on Nov 15, rainfall of 59.5mm was recorded due to the interaction between the circulation of Podul and cold surge. Totally, rainfall from TD 05VN and TC Podul (179.5 mm) as higher than mean rainfall (150.0 mm) over 39 years and it accounted for about 38.0% precipitation in wet season. Consequently, precipitation from TD/TC which affected to Phan Rang city contributed in the range of 37% to 145% to local rainfall budget in wet season.

Annually, TDs and TCs significantly increase the precipitation for the savanna climate areas of Phan Rang city, as well as Ninh Thuan province. In 2010, rainfall contributions from TC/TD accounted for about 47% of annual precipitation and 90% of mean annual climatological precipitation. The same figures are 29% and 38% in 2012; 20% and 24% in 2013; and 6% and 3% in 2014 (Table 3). In the absence of TC/TD as in 2011 and 2015, the total annual rainfall is less than 1000 mm.

Considering SPI-3 variation during 2010-2015 (Fig. 4), SPI-3 in the period of 2010 – 2013 was in range of -1.0 to more than 2.0. This means that Phan Rang was almost in normal condition, and sometimes in very wet or extremely wet condition due to the effect of TC/TD event such as after January and November 2010, April 2012. Some other high peaks of SPI were due to other reason like cold surge, ICTZ and so on. Overall, the values of SPI-3 during the TC/TD events

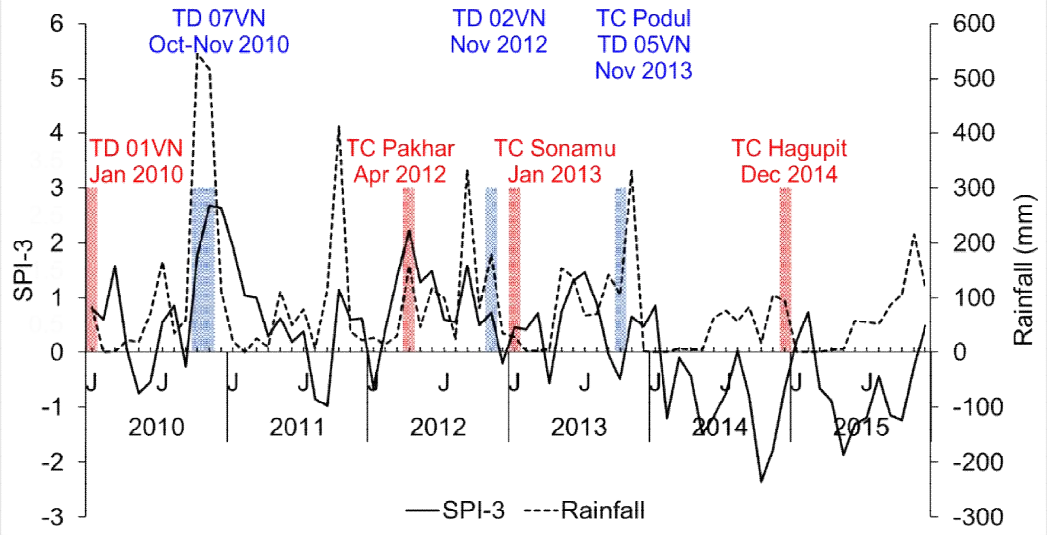

Fig. 4. The variation of SPI-3 at Phan Rang station, Ninh Thuan province, Vietnam during 2010-2015 (Red Bar: Dry season; Blue bar: Rainy season)

were above 0.45 (normal condition). In contrast, SPI-3 in 2014 and 2015 were in range of -2.34 to 0.73, which means it was in moderately dry condition and sometimes in severely and extremely condition. TC Hagupit occurred in Dec 2014 and it partly improved dry condition when SPI-3 decreased from -2.34 (Oct 2014) and -1.77 (Nov 2014) to -0.68 (Dec 2014), 0.21 (Jan 2015) and 0.73 (Feb 2015). Because TC Hagupit just brought a small rainfall amount (28.8mm), it was not adequate to recover prolonged drought condition in this area over the whole year. In additions, total rainfall in 2015 was 82% of mean annual rainfall with no supporting rainfall from TC/TD, which made Phan Rang experienced one of the worst drought disasters during 2014-2015. The drought condition made a serious water shortage for irrigation and domestic uses in this region and it lasted until mid-2016.

4. CONCLUSION

Although TC/TD causes destructive and deadly damage to the places it passes, it also provides some economic and ecological advantages. This paper pointed out some of the possible benefits from TC to due meteorological drought condition in Ninh Thuan Province. TC/TD has increased total rainfall and reduces the drought condition in Phan Rang, Ninh Thuan. TC/TD could cause the flooding in the area where it is passed, but the weak TC and TD can contribute to the total rainfall of 7 – 40% in dry season and 37 - 145% in wet season or 3 – 39% of annual climatological rainfall. As the results, it helps to reduce the drought condition and to provide benefit for agriculture development in Ninh Thuan. Therefore, based on the daily/extreme weather forecaster, local authorities can control and recommend short-term recommendations so that local people can take advantage of the benefits of TC/TD sustainably, especially in drought areas.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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