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Study on Droughts in the South Central and the Central Highlands

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Abstract. This paper presents research findings and drought zoning of South Central and Central Highlands. Meteorological, hydrological and agricultural drought indices were calculated for drought zoning, drought mapping and severity assessment of drought types, from which recommendations were given for monitoring and remedying the effects of droughts, contributing to socioeconomic development, improving people's lives of South Central and Central Highlands.
Keywords: Meteorological, hydrological, agricultural drought indices, drought zoning.

1. Background

Drought is a normal, recurring feature of climate. Drought occurs when less than normal rainfall is received over an extended period of time, such as a season or longer. Drought can also occur when there is higher than normal temperature in a long time. Other causes of drought may be the delayed rainy season or precipitation period associated with growing seasons of major crops. Strong winds and low relative humidity can make the case worse. Human activities often significantly aggravate the effects of drought when higher water use is at the same time with reduced natural water supply [1].

There are four approaches often used to assess drought level, namely meteorological, hydrological, agricultural and socioeconomic droughts. Three first three approaches consider drought as a physical phenomenon. The last approach refers to the drought in the supply and demand context, tracking the effects of water shortages [2].

2. Study Method

2.1. Meteorological Drought

Meteorological drought is defined as a rainfall deficit in relation to some average amount. The definition must be considered as a region specific, based on the understanding of the region climate, as meteorological data are often the first indicator of droughts. Indices for meteorological droughts include: Dry index (K_n); Standardized Precipitation Index (SPI),

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Percentage of Normal Rainfall (TC); Effective Drought Index (EDI).

$$EDI = DEP/SD\ (DEP)$$

$$DEP = EP - MEP$$

$$EP_i = \sum_{n=1}^{i}\left[\left(\sum_{m=1}^{n} P_m\right)/n\right]$$

Where EPi = valid effective precipitation, Pm = daily precipitation, m = number of days before a specific day, EP = effective precipitation for 365 days counting from a specific day, DEP = deviation of EP from MEP [3] (Mean Effective Precipitation, a 30-year mean of the EP for each calendar day).

Effects of droughts occurred a few years ago on the soil are reflected in EDI index. EDI index is a function of precipitation needed for the return to Normal conditions (PRN). PRN is precipitation needed to offset the loss of accumulated precipitation since the start of a drought, PRN is derived from actual effective precipitation (EP) and its standard deviation compared to the average value of each months. Ranks of EDI reflect drought conditions shown in Table 1.

Table 1. The classification of meteorological drought by EDI [3]

TT	EDI	Drought classification
1	< -2.0	Extreme Drought
2	-1.99 < EDI < -1.5.0	Severe Drought
3	-1.49 < EDI < -1.0	Moderate drought
4	-0.99 < EDI < 0.99	Normal conditions

2.2. Agricultural Drought

Agricultural drought occurs when there is not enough soil moisture to meet the needs of a crop at a time. Agricultural droughts occur after meteorological but before hydrological droughts. Agricultural drought is often judged by the following indices: MAI; SAI; WRSI; CMI; Soil moisture dryness (Sd); field water balance.

In this study, Crop Moisture Index (CMI) was used to establish drought severity maps for South Central and Central Highlands, with the following formula:

CMI = (ET - PET)

Where ET= actual evapotranspiration (mm) calculated basing on temperature, weekly precipitation and soil moisture at surface and subsurface; PET = Potential evapotranspiration (mm). Time periods for the calculation are weeks and months. Threshhold values of the index are: > 3.5: very wet; 2.5 to 3.49: severe wet; 1.0 to 2.49; Moderate wet; -1.24 to 0.99; Nearly normal; -1.99 to -1.25: light to moderate drought; -2.74 to -2.0: Severe drought; -2.75: Extreme drought [1, 2, 4]

2.3. Hydrological Drought

Hydrological drought refers to deficiencies in surface and subsurface water supplies. It is measured as streamflow, and as lake, reservoir and groundwater levels. There is usually a delay between the lack of rain and less measurable water in streams, lakes and reservoirs. Therefore, hydrological measurements are not the first indicator of a drought. When rainfall decreases or rainfall deficit takes place over an extended time period, the shortage will be reflected by the reduced surface water and reduced groundwater [2, 4].

Table 2. Classification of hydrological drought by SWSI [2]

SWSI	Water supply status
≤ -4,0	Extreme drought
-4,0 ÷ -3,0	Severe drought
-2,9 ÷ -2,0	Moderate drought
-1,9 ÷ -1,0	Mild drought
-0,9 ÷ 0,9	Near normal
1,0 ÷ 1,9	Slightly wet
2,0 ÷ 2,9	Moderate wet
3,0 ÷ 4,0	Very wet
≥ 4,0	Extremely wet

Commonly used hydrological indices include: Streamflow deficit index, Streamflow drought index; Dry index; Surface water supply index (SWSI).

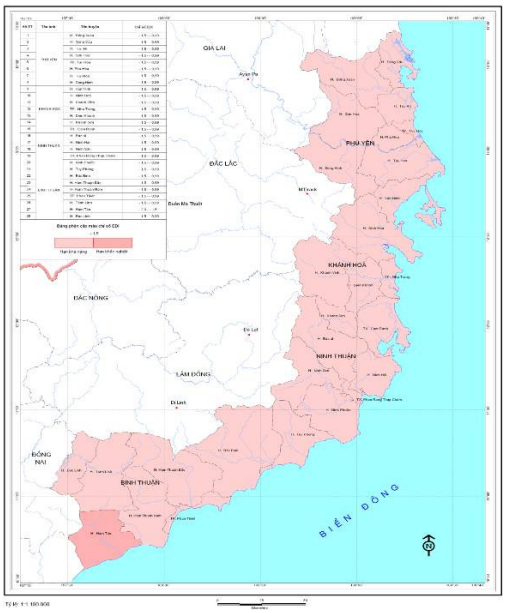
$$SWSI = \frac{aP_{snow} + bP_{rain} + cP_{strm} + dP_{resv} - 50}{12}$$

Where: a, b, c, d = weights for snow, rain, streamflow and reservoir storage respectively (a + b + c + d = 1); P_{snow}, P_{rain}, P_{strm} and P_{resv} = probability (%) of non-exceedance for each of these four water balance components, respectively (P {X ≤ A}). The classification of hydrological drought index SWSI is presented in Table 2.

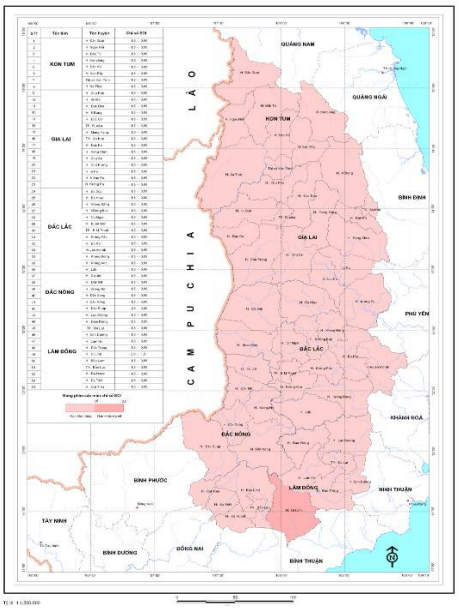
3. Results

3.1. Meteorological Drought Severity

The zoning map of the meteorological drought severity for the dry season in South Central and Central Highlands is presented in Figure 1.



(a) South Central



(b) Central Highlands

Figure 1. Drought severity map by EDI.

South Central: In the North: In 8 districts of Phu Yen province, EDI index is in the range of -0.99 to -1.5, moderate meteorological drought; in 7 districts of Khanh Hoa, SDI is from -0.99 to -1.5, moderate meteorological drought. In the South: In 5 districts of Ninh Thuan, EDI index is ranged from -0.99 to -1.5, quite moderate meteorological drought; Among 8 districts of Binh Thuan, EDI index of 7 districts fluctuates from -0.99 to -1.5, moderate meteorological drought; One district (Ham Tan) has EDI index ranged from -1.55 to -2.0, severe drought level. Thus, in 27 districts in South Central, in 10 dry seasons (from December to August of the following year), about 5 meteorological droughts occurred at moderate levels, in particular, Ham Tan district experienced the severe drought.

Central Highlands: In the North: in 8 districts of Kon Tum province, EDI index ranged from -0.99 to -1.5, the drought is quite moderate; in 15 districts of Gia Lai province, EDI index ranged from -0.99 to -1.5, quite moderate drought level. In 13 districts of Dak Lak province, EDI index ranged from -0.99 to -1.5, moderate drought level. In the South: In the 6 districts of Dak Nong province, EDI index ranged from -0.99 to -1.5, moderate drought; In 12 districts of Lam Dong province, 11 districts have EDI index ranged from -0.99 to -1.5, moderate drought level, in particular, this index of Di Linh district is lower, from -1.5 to -2.0, reaching severe drought level. Thus, in 53 districts of Central Highlands, in 10 dry season, (from December to August of the following year), about 5 meteorological droughts occurred at moderate level, Di Linh district in particular, experienced severe meteorological drought.

3.2. Hydrological Drought Severity

Average monthly streamflow deficit ratio

At frequency of p = 25%: Moderate, severe and very severe droughts in rivers often occur in the months of Feb - May, occasionally in Jun - Sep in South Central. Severe droughts in majority of rivers appear in the months of Mar - Apr; particularly they may also appear in Feb in Krong Buk River (station Bridge 42) and in Jan-Feb in Luy River (Luy River Station). At frequency of P = 50%: Droughts usually occur in the months of Mar - Apr, and may appear in Jun - Sep in South Central region. Severe droughts often take place during the period of Mar - Apr at some rivers (in Apr at Ba River - Cung Son station and at Dak Nong River - Dak Nong station. At frequency of p = 75%: Droughts appear only in some months. In South Central, droughts mainly occur in the months of Mar - May, in some cases they may even last until Jun – Aug. Severe droughts occur only in Luy River (Feb - Mar) and La Nga River (Ta Pao station in Mar).

Monthly dry index

Monthly dry index of two stations representing South Central and Central Highlands is shown in Table 3.

Table 3. Dry index K_{han} of two representative stations

Song Luy hydrological station: South Central								
Months	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Average	0.832	0.886	0.844	0.75	0.082	0.046	0.03	0.631
Max	0.922	0.927	0.924	0.928	0.404	0.571	0.362	0.91

Year	2005	2005	2003	2005	1995	1983	1984	2004
Min	0.571	0.79	0	0	0	0	0	0
Year	2001	2001	1982	1999	1982	1981	1981	1998
Bridge 42 hydrological station: Central Highlands								
Months	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	
Average	0.571	0.812	0.82	0.477	0.107	0.083	0.064	
Max	0.974	0.989	0.993	0.96	0.724	0.523	0.634	
Year	2005	2005	2005	2002	1985	1986	1981	
Min	0	0.313	0.155	0	0	0	0	
Year	1982	1997	1989	1982	1981	1981	1982	

Slightly low streamflow, (with K_{can} = 0:51 to 0.7) may occur annually during low flow season. Moderately low flow (K_{can} > 0.70) usually occurs in the months of Jan to May - Jun at rivers of the Central Highlands and can last until the end of Sep at rivers of South Central. Moderately low flows with the frequency of 30% or higher occur in the months of Feb - May, even in Aug, Sep in South Central's Rivers.

Hydrological droughts may occur in all months in the dry season, but more frequently in the months of Jan - May and possibly in Jul, Aug in South Central. Moderate droughts (K_{han} = 0.81 to 0.95) mainly occur in the months of Jan - Apr at rivers in the northern and central Central Highlands (Kon Tum, Gia Lai, Dak Lak), in the months of Jan - Mar in southern Central Highlands (Lam Dong, Dak Nong), in the months of Feb – Apr, Jul in South Central, particularly in the southernmost central region (Ninh Thuan, Binh Thuan) they usually occur in the months of Jan - Apr and Dec. Extreme droughts (K_{han} > 0.95) appear only in Krong Buk River at Bridge 42 station.

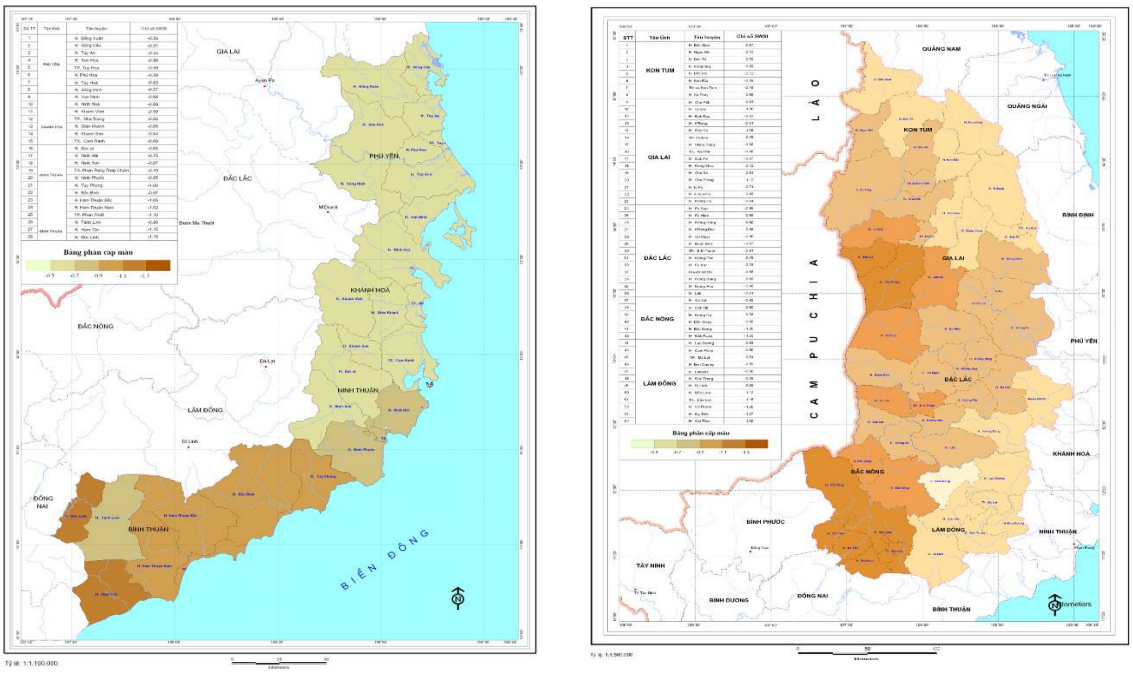
Water Supply Index (SWSI)

SWSI index (Table 4) of most of river basins shows that in the years with moderate and severe drought (1983, 1998, 2005) the values of SWSI are consistent with other drought indices: In 1983 the minimum value of SWSI at An Khe K_{SWSI} = -3.52 in Feb, at Ban Don K_{SWSI} = -3.39 in May, at Bridge 14 K_{SWSI} = -2.29 in May. In the year of 1998, the smallest value of SWSI at An Khe K_{SWSI} = -1.58 in Feb, at Ban Don K_{SWSI} = 3.31, -3.53 in March, Apr, at Bridge 14 K_{SWSI} = -3. 37, 3, 13 in the month of Mar – Apr. In 2005, the lowest value of the index SWSI at An Khe K_{SWSI} = -2.56 in Jan, at Ban Don K_{SWSI} = -3.91 in Feb, in Bridge 14 K_{SWSI} = -3.83 in Jan and Mar, Apr.

In catchments with reservoir, drought conditions are less stressed, with the drought levels in the driest months of typical dry years 1983, 1998, 2005 at moderate level; the average value for the low flow season is at mild drought level. Specifically, in the districts beneficial from the reservoirs, drought level is reduced.

Table 4. Drought classification by Surface Water Supply Index (SWSI)

TT	Hydrological stations	Time interval	Low flow season	Percentage of annual drought occurrence			Drought Severity Index
				Mild	Moderate	Severe	
				-2< K<-1	**-3<K<-2**	**K<-3**	**DSI**
1	Dak Mot	Month	XII, I- VI	27.27	14.29	11.69	22.7
2	Trung Nghia	Month	XII,I- VI	38.8	16.3	18.4	31.6
3	Kon Plong	Month	I- VII	27.3	18.2	9.1	22.7
4	Kon Tum	Month	I- VII	12.0	10.3	5.7	12.4
5	Krong Buk	Month	I- VIII	10.3	12.6	3.4	11.4
6	Giang Son	Month	I- VII	18.0	10.0	4.5	12.9
7	Duc Xuyen	Month	I- VIII	8.0	4.6	1.7	5.6
8	Thanh Bình	Month	XII, I- VI	13.1	4.6	4.6	9.0
9	Dai Nga	Month	XII, I- VI	13.1	5.7	2.9	8.3
10	Ta Pao	Month	XII, I- VI	22.2	22.2	4.0	19.6
11	Dak Nong	Month	XII, I- VI	36.8	24.3	6.9	26.6
12	An Khe	Month	XII, I- VII	12.5	9.5	3.5	10.5
13	Song Hinh	Month	I- IX	28.3	18.2	6.1	20.7
14	Dong Trang	Month	I- IX	11.6	7.2	4.8	10.1
15	Song Luy	Month	XII, I- VII	6	4.5	3	6.0



(a) South Central (b) Central Highlands

Figure 2. Map of drought severity by SWSI.

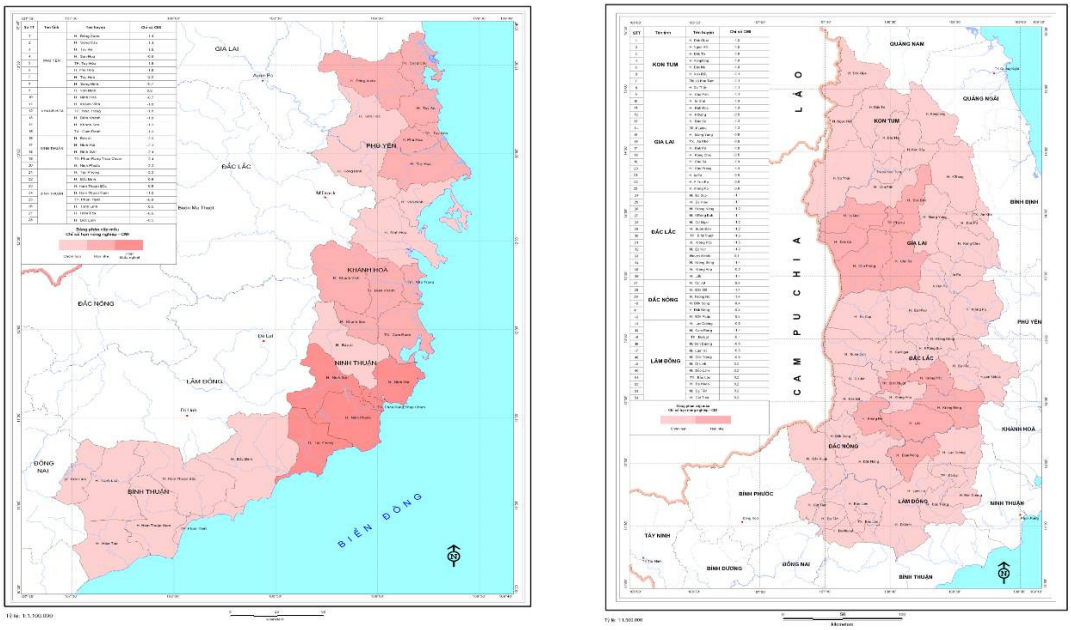
3.3. Agricultural Drought Severity

In South Central: In the dry season (Dec - Aug), extreme drought does not happen, while severe droughts occur in 25% of districts, mild to moderate drought accounts for 36% of districts. No droughts condition or moisture availability for crops (maize) are found for the 44% of the remaining districts.

In Central Highlands: In the dry season (Dec – May), neither extreme nor severe droughts occurred. Moderate and mild droughts occur in 19% of districts. No droughts condition or moisture availability for crops (maize) are found for the 81% of the remaining districts.

Table 5. Severity of agricultural drought by CMI

Region	Number of districts affected by agricultural drought								Entire region	
	No drought		Mild and Moderate drought		Severe drought		Extreme drought			
	No of districts	Percent (%)	No of districts	Percent (%)	No of districts	Percent (%)	No of districts	Percent (%)	No of districts	Percent (%)
South Central	11	39%	10	36%	7	25%	0	0	28	100
Central Highlands	44	81%	10	19%	0	0	0	0	54	100



(a) South Central (b) Central Highlands

Figure 3. Severity of agricultural drought.

4. Conclusions

From the research results on severity assessment of meteorological, hydrological and agricultural droughts for South Central and the Central Highlands, the following conclusions can be drawn:

Meteorological drought: *In South Central:* Droughts are less prominent in the northern districts compared to those in the south. The southernmost districts experience more severe droughts but with shorter time period due to the fact that in many years, the rainy season in the location begins as early as in late April. *In Central Highlands:* meteorological droughts in the northern districts are more severe compared to those in the south where the rainy season in many years begins already in late April.

Hydrological drought: Streamflows with slightly low level (K_{can} = 0.51 - 0.7) may occur in dry season every year. Moderately low flow level (K_{can} > 0.70) often occurs in the months of Jan – May, Jun on the rivers in the Central Highlands and lasts till the end of Sep on the rivers of South Central. Moderate droughts (K_{han} = 0.81 to 0.95) mainly occur in the months of Jan – Apr on the rivers of northern and central of Central Highlands, the months of Jan – Mar in the southern Central Highlands; the southernmost Central (Ninh Thuan, Binh Thuan) in particular, experienced drought in Jan – Apr and Dec. Extreme drought (K_{han} > 0.95) is observed at Krong Buk river at Bridge 42 station. In moderate and severe drought years, values of SWSI are well consistent with other drought indices. These indices at the same time show the important role of reservoirs in reducing hydrological drought severity.

Agricultural drought: This is the first time CMI has been applied for South Central and Central Highlands. The comparison of calculated and the observed agricultural droughts shows that the index well reflects well actual agricultural droughts in those two areas. However, in order to be able to calculate CMI, it is needed to have data on actual and potential evapotranspiration which are often not included in the regular observation scheme of the current hydrometeorological station network. It is, therefore, necessary to study on methods for actual and potential evapotranspiration calculation.

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