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Projection of extreme temperature and precipitation and their impacts on water resources in Dong Nai river basin and vicinity – Viet Nam

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Abstract - **Extreme climatic events in Viet Nam are expected to increase in both frequency and intensity due to climate change. Extreme temperature and rainfall are projected by using Regional Climate Model (RCM) CCAM to dynamically downscale from 5 Global Climate Models (GCMs) for scenarios RCP8.5 and RCP4.5, in the 21th century and their potential impacts on water resources in Dong Nai river basin and vicinity areas. The result shows a significant rise of daily maximum and minimum temperature compared with the based period, especially in Vung Tau station. Number of days with maximum temperature above the 90th percentile and 35°C tends to increase, higher rate in higher average temperature stations. Number of days with minimum temperature exceeding 90th percentile also increases evenly across all stations. Although maximum 1-day, 3-day, 5-day precipitation at all other stations are in the upward trend, the changes in Bao Loc and Phan Rang station are unclear. It is supposed that this projection of extreme temperature and rainfall in the future will lead to some types of natural disasters related to water resources in this area, such as floods, droughts, salinity intrusion.**

Keywords— Extreme climatic events, dynamical downscaling, water resources, Dong Nai river basin and vicinity areas.

I. Introduction

Dong Nai river basin and vicinity (DNRBV) is an important region that plays a crucial role in socio-economic development of the Viet Nam's Southern region. Located on a total area of 49643.53 km^2, consisting 11 provinces/cities: Dac Nong, Lam Dong, Binh Phuoc, Binh Duong, Dong Nai, Tay Ninh, Ho Chi Minh City (HCMC), Long An, Ninh Thuan, Binh Thuan and Ba Ria-Vung Tau, DNRBV has a relatively mild and stable climate condition [3]. However in recent years, DNRBV has been suffering from natural disasters and extreme climatic events (ECEs). These events have direct impacts on water resources in the basin, causing changes in hydrological regime, extreme floods, droughts, and salinity intrusion..., all of which heavily affected people's livelihood and socio-economic activities.

This paper presents results of projection of extreme temperature and rainfall, and their potential impacts on water resources in DNRBV. The findings are the basis to facilitate further researches on quantitative assessment of impacts of ECEs on water resources, and thereby drawing out water resources and disaster risk management strategies for the river basin under the context of climate change.

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II. Methodology

A. *ECEs analysis methods*

ECEs are defined as "*the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable*." [8]

In 1997, a group of experts from World Meteorological Organization (WMO) known as ETCCDI developed a general ECEs set including 27 indices related to extreme temperature and precipitation in order to apply to different regions and countries [10]. In Viet Nam, depending on the research goals in different areas, there have been many studies that developed various indices for assessing ECEs. Typically, in SREX Viet Nam [6], the climate experts evaluated trends and magnitude of ECEs' change in the whole of Viet Nam based on 3 groups: (i) Extreme weather and climate factors; (ii) Large-scale circulations that affect the occurrence of ECEs (monsoon, El Niño, hurricanes, ...); (iii) ECEs' impacts on the natural physical systems (drought, flooding, salinity, ...).

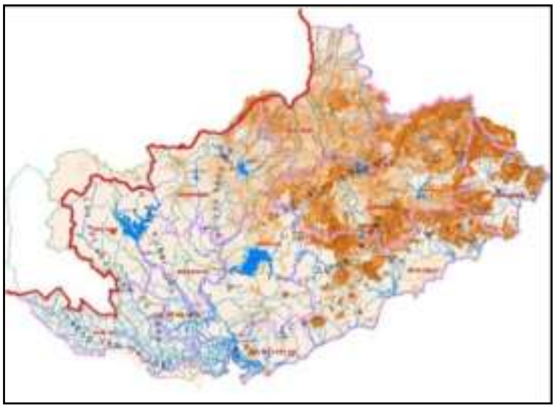

Figure 1. Dong Nai River Basin and Vicinity (DNRBV)

In this paper, to analyse the impacts of ECEs on water resources in DNRBV, the authors focus on indices related to temperature and precipitation extreme factors presented in *Table 1*. We consider the large-scale circulations as the derivation and the phenomena such as droughts, flooding, and salinity intrusion… as the impacts of these climate extreme factors.

B. *Data collection*

This paper projects the development of ECEs in DNRBV based on analysing temperature data at 5 meteorological stations (Bao Loc, Da Lat, Dong Phu, Phan Thiet, Vung Tau) and rainfall data at 8 rain stations (Bao Loc, Da Lat, Phan Thiet, Tay Ninh, Tri An, Tan Son Nhat, Vung Tau,

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Phan Rang) which are representatives for different climate zones in the basin.

[redacted]SELECTED INDICES

Indices	Unit	Definitions
TXx	°C	Monthly maximum value of daily max temperature
TNn	°C	Monthly minimum value of daily min temperature
TX90p	%	Percentage of time when daily max temperature > 90th percentile
TN90p	%	Percentage of time when daily min temperature > 90th percentile
SU35	days/year	Annual count when daily max temperature > 35 ◦C
Rx1day	mm	Monthly maximum 1-day precipitation
Rx3day	mm	Monthly maximum consecutive 3-day precipitation
Rx5day	mm	Monthly maximum consecutive 5-day precipitation
CDD	days	Maximum number of consecutive days when precipitation < 1mm

- Climate data for the based period: daily temperature and rainfall values observed at above stations in the period of 1986-2005.

- Climate simulated data: daily temperature and rainfall values which are the output of Regional Climate Model CCAM (developed by Commonwealth Scientific and Industry Research Organisation - Australia) dynamically downscaled from 5 Global Climate Models (ACCESS1-0, CCSM4, CNRM-M5, GFDL-CM3, MPI-ESM-LR, NorESM1-M). It is chosen the two most particular scenarios: RCP8.5 and RCP4.5 according to the 5th Assessment Report of the IPCC (AR5) [9] for simulated run in the periods: 1986-2005 for control simulated run, 2046-2065 for projected run in the middle of 21st century, 2080-2099 for projected run in the end of 21st century.

C. *Bias correction methods*

The bias correction for RCMs results is necessary as the RCMs-simulated climate data are considerably different from the observed [5]. Recently, several bias correction methods have been developed, such as Linear scaling of precipitation and temperature which corrects only mean value of the time series [12], Power transformation of precipitation [11] and Variance scaling of temperature [4] to adjust both mean and variance of the time series; Local intensity scaling of precipitation [13] which focuses on the frequency of wet days; Quantile mapping [7] keeps the distribution function of RCM-simulated climate values to agree with the observed ones, etc.

This paper uses the method of correcting both variance and mean values for temperature time series and combined with adjusting wet days frequency for precipitation time series. The basis of variance and mean values correction method is to ensure that both those values of the corrected control run and the observed one are the same.

The method used for temperature dataset is presented in [4]. *Figure 2* shows the correcting results of ACCESS1-0-CCAM run of January daily maximum temperature data at Bao Loc station in the based period.

For rainfall dataset, before being corrected of mean and variance values according to [11], frequency of wet days is adjusted to fit with reality using method in [13]. *Figure 3* is correction result of NorESM1-M-CCAM run of monthly rainfall at Tay Ninh station in the based period.

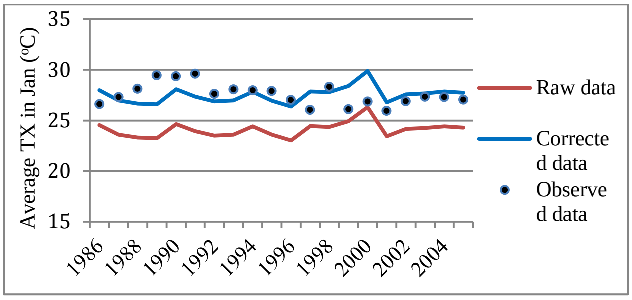

Figure 2. Average of daily max temperature in Jan (1986-2005) simulated by ACCESS1-0-CCAM in Bao Loc station before and after correction

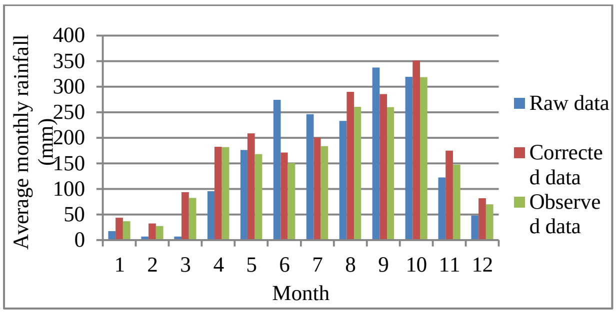

Figure 3. Average monthly rainfall simulated by NorESM1-M-CCAM at Tay Ninh station before and after correction compared with the respective observed value.

III. Results

A. *Change of extreme temperature values*

The DNRBV is located in Southeast Region of Viet Nam, the average annual temperature is relatively high and stable (21.3-27.6^{0}C). April and May are the hottest months with the average temperature of 22.9-29.1^{0}C, January is the coldest month with 19.4-26.5^{0}C. There is a reduction of temperature associated with altitude distribution due to topographic influence [3].

Table 2 indicates projected magnitude of change of extreme temperature values in the middle and the end of 21st century compared with the observed data in based period ("+" is positive and "-" is negative magnitude).

- TXx: The positive magnitude of change occurs in every representative station. The largest increase is found at Bao Loc station, with 2.44-2,59°C and 2,54-4,71°C in the middle and the end of the century, respectively**.** The smallest increase is at Phan Thiet station, with 0,93-1,35°C in the middle and 1.32-3.08°C at the end of the century. It is proved that the increasing level in TXx depends on average temperature distribution. Higher temperature areas tend to have higher increasing level. The distribution of increasing level of months in a year is unclear.

- TNn: similarly, TNn in all stations increase, of which the largest magnitude is at Dalat station with 1.71-2.32°C in the middle and 2.14-4.22°C in the end of 21st century. The lowest increase, with RCP4.5 scenario, occurs at Bao Loc station, while with RCP8.5 scenario, occurs at Vung Tau and Dong Phu stations. It shows that the increasing level of TNn is not obvious spatially distributed. For temporal distribution, the increasing magnitude is largest in November and December, and is smallest in February and March at most stations.

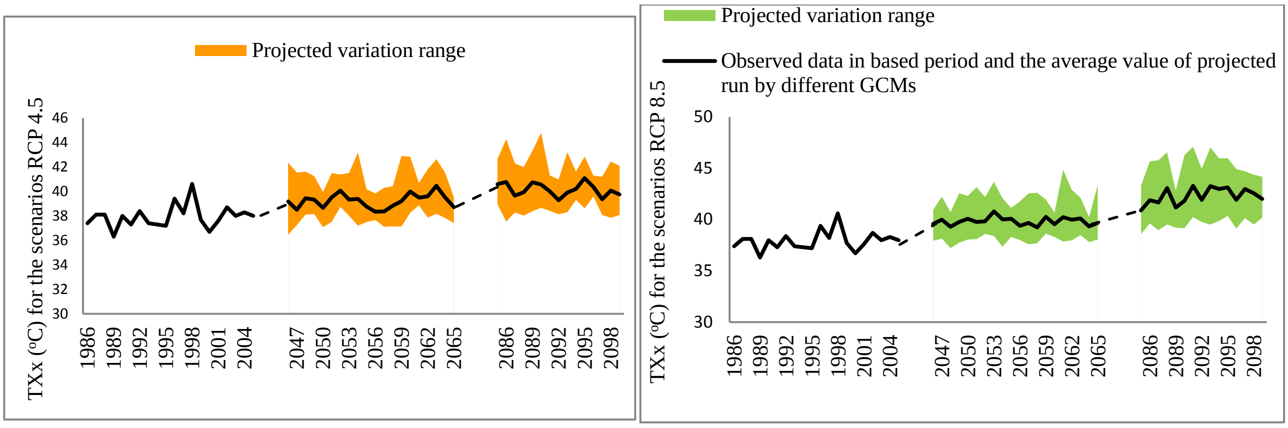

Figure 4. Projected variation range of TXx in March for the scenarios RCP 4.5 (left figure) and RCP 8.5 (right figure) at Dong Phu Station.

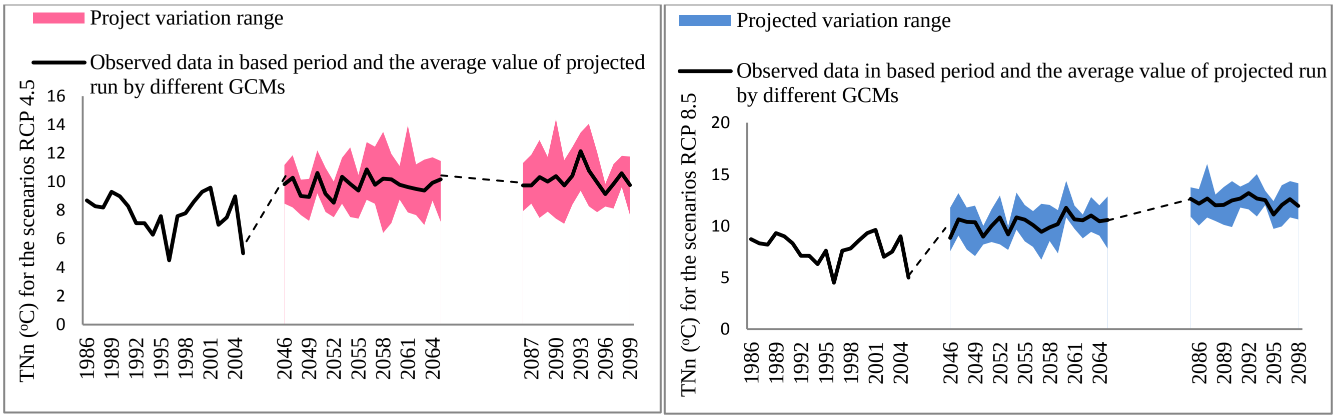

Figure 5. Projected variation range of TNn in January for the scenarios RCP 4.5 (left figure) and RCP 8.5 (right figure) at Da Lat Station

[redacted] PROJECTED EXTREME TEMPERATURE COMPARED TO THE BASE PERIOD, FOR THE SCENARIOS RCP4.5 (ABOVE) AND RCP8.5 (BELOW)

RCP4.5	**In the middle of the 21st Century (2046-2065)**					**In the end of the 21st Century (2086-2099)**				
	TXx (ºC)	***TX90P (%)***	***SU35 (day/year)***	***TNn (ºC)***	***TN90P (%)***	***TXx (ºC)***	***TX90P (%)***	***SU35 (day/year)***	***TNn (ºC)***	***TN90P (%)***
Bao Loc	2.4	30.7	4.6	1.1	30.9	2.5	32.1	2.0	1.5	39.0
Da Lat	1.7	23.7	0.0	1.7	28.9	2.2	33.9	0.0	2.1	38.1
Dong Phu	1.9	16.5	83.0	1.1	27.2	2.4	24.3	114.3	1.5	37.7
Phan Thiet	0.9	18.5	17.6	1.2	27.2	1.3	27.2	28.8	1.6	37.4
Vung Tau	1.1	24.8	7.7	1.1	19.1	1.5	35.5	13.8	1.6	28.1
RCP8.5										
Bao Loc	2.6	33.4	1.2	1.7	41.6	4.7	61.8	24.2	3.7	66.6
Da Lat	2.2	33.8	0.0	2.3	41.4	4.2	61.0	0.8	4.2	69.0
Dong Phu	2.5	25.9	117.9	1.6	39.5	4.5	53.8	165.2	3.5	70.1
Phan Thiet	1.4	28.3	32.8	1.7	40.1	3.1	61.4	96.4	3.5	71.7
Vung Tau	1.5	37.1	15.9	1.7	30.0	3.2	72.0	70.2	3.2	67.9

- TX90P and SU35: the percentage of number of year-days which has maximum temperature exceeding 90th percentile increases drastically at all stations, especially at Vung Tau station with the increase from 24.8 to 37.1% and from 35.5 to 72% in the middle and the end of the century, respectively. The number of days exceeding 35°C increases dramatically at stations where have relatively high average temperature, typically at Dong Phu station, with the increase of 117.9 days/ year in the middle and 165 days/year in the end of the century. Meanwhile there is no so significant increase at stations where have relatively low temperature.

- TN90P: the percentage of number of year-days which has minimum temperature exceeding 90th percentile also increases quite evenly across all stations.

B. *Change of extreme precipitation values*

The average rainfall across DNRBV is approximately 1.950 mm, which is moderate compared to the country's average, however, unevenly distributed in space and time. Regarding temporal distribution, in the whole basin, the rainy season lasts for seven months from May to November which accounts for 81.8 - 96.3% of the total annual rainfall volume. Firstly, extreme rainfall causes floods. Floods in DNRBV depend on the intensity and the maximum daily/ consecutive multi-day precipitation.

- Rx1day: tends to increase at all stations with higher level in the middle than in the end of the century. The increasing level is also relatively different between stations. There is a dramatically rise at Tri An and Vung Tau stations with increase of 40.19 - 55.97% in the middle, and 30.69 -

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44.07% at the end of the century. Da Lat station has the least significant change, the trend is not clear in the middle and only increase 3.06 - 7.71% in the end of the century.

- Rx3day: increases at all stations, especially in the end of the century. Similarly to Rx1day, Vung Tau station has the largest increase of 30.49 - 43.61% in the middle and 34.45 - 44.07% in the end of the century. Bao Loc station has smallest increase of 4.69 - 12.62% and 10.34 -11.55 in the middle and the end of the century, respectively.

- Rx5day: Apart from Bao Loc and Phan Rang stations with unclear trend, the other stations are likely to increase of which Vung Tau station has the most increases of 25.58 - 38.88% in the middle and 30.95 - 40.62% in the end of the century.

The increasing level of extreme rainfall causing flood mainly occurs in rainy season. Therefore, it is supposed that the rising of flood risks would happen in both intensity and frequency in the basin.

Regarding extreme rainfall causing drought, it is CDD. In overall, January and February are the driest months in the year and South Central Coastal region (Phan Rang and Phan Thiet stations) are the driest area in DNRBV. According to future predictions, CDD at all stations are expected to decrease, especially in the above arid regions (33.79-37.21 days/year in Phan Rang and 67.41-73.32 days / year in Phan Thiet stations). The decrease mainly occurs in the dry months.

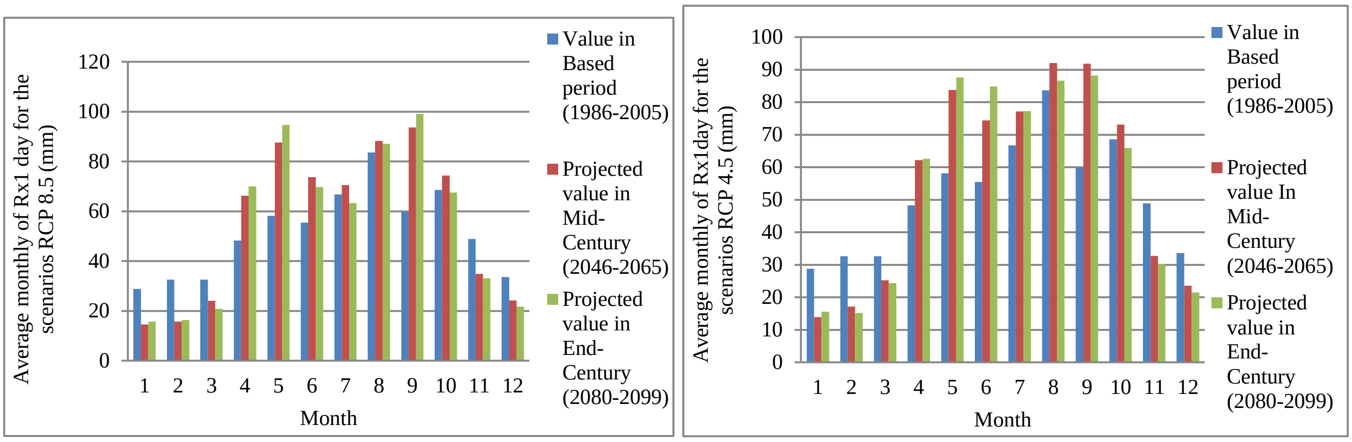

Figure 6. Monthly changing rate of Rx1day in the middle and the end of the 21st Century according to scenarios RCP4.5 (left figure) and RCP8.5 (right figure) compared to the based period at Bao Loc station.

[redacted]PROJECTED EXTREME PRECIPITATION COMPARED TO THE BASED PERIOD, FOR THE SCENARIOS RCP4.5 (ABOVE) AND RCP8.5 (BELOW)

RCP4.5	**In the middle of the 21st Century (2046-2065)**				**In the end of the 21st Century (2086-2099)**			
	Rx1day (%)	***Rx3day(%)***	***Rx5day (%)***	***CDD (day)***	***Rx1day (%)***	***Rx3day (%)***	***Rx5day (%)***	***CDD (day)***
Bao Loc	15.75	4.69	-0.43	-14.50	20.85	11.55	4.78	-14.31
Da Lat	-0.88	28.13	24.56	-17.14	3.06	31.34	25.12	-16.53
Phan Rang	9.04	10.42	-0.19	-35.87	16.14	16.95	7.36	-37.21
Phan Thiet	15.98	12.63	8.78	-69.08	17.56	16.13	14.23	-67.41
Tan Son Nhat	37.90	24.59	20.89	-40.63	38.24	22.47	14.78	-38.73
Tay Ninh	17.68	18.24	10.17	-48.92	29.82	28.46	18.56	-49.09
Tri An	49.03	35.27	27.63	-67.43	42.01	30.69	23.20	-65.68
Vung Tau	42.49	30.49	25.58	-79.43	38.66	34.45	30.95	-77.63
RCP8.5								
Bao Loc	17.90	12.62	3.96	-14.21	18.89	10.34	5.72	-17.72
Da Lat	2.01	27.86	24.15	-17.02	7.71	30.69	26.69	-19.77
Phan Rang	18.72	16.92	4.67	-37.19	17.39	20.67	11.19	-33.79
Phan Thiet	17.97	14.70	12.65	-69.18	59.01	46.78	40.90	-73.32
Tan Son Nhat	40.03	29.43	21.23	-40.80	63.95	45.10	34.22	-43.05
Tay Ninh	22.45	23.28	14.12	-51.44	48.64	38.74	25.57	-54.28
Tri An	40.19	28.32	21.81	-67.83	45.19	31.67	26.03	-71.48
Vung Tau	55.97	43.61	38.88	-81.50	56.83	44.07	40.62	-81.24

IV. Impacts of ECEs on water resources in DNRBV

The variation of temperature and rainfall in DNRBV results in the changes of disasters related to water resources in both frequency and intensity.

A. *Impacts of ECEs on floods*

In DNRBV, the probability of maximum average daily discharge of the sub-basins and the occurrence frequency of the largest flood peaks is supposed to have temporal correlation [3]. This proves that the variation of the river flow is not only closely related but also highly sensitive to changes in precipitation in the basin. Some typical floods occurred in the basin such as in 1932, 1952, 1964, 1978, 1996, 1999, and 2000. As the projected results mentioned above, maximum 1-day, 3-day and 5-day rainfall volume tend to increase. Thus, there is high possibility of major floods to occur more frequently in areas such as Cat Tien, Ta Lai (Lam Dong province), Phu Dien (Dong Nai Province); Vo Xu, Tanh Linh, Duc Linh (Binh Thuan) areas.Impacts of ECEs on flash floods

It is often affected by the inter-tropical convergence zone combined with the occurrence of strong southwest monsoon at the beginning of the rainy season that causes intense rainfalls lasting for 2-3 days with the total rainfall volume of 200-300 mm or even greater, In DNRBV. Under such circumstances, the occurrence probability of major floods and flash floods becomes more considerable. Places with flash floods experiences include Ninh Thuan, Binh Thuan, Dak Nong and Lam Dong province. Some typical flash floods happened in 1993 in Ca Ty River, Phan Thiet or in Dinh River in 1999 have caused heavy damages to people and properties [1]. According to the rainfall estimates in the middle and the end of the century, maximum consecutive 3-day and 5-day rainfall tend to increase in these areas, especially at Phan Thiet station. This is the signal that warns the rising of flash flood frequency.

B. *Impacts of ECEs on drought*

Drought and serious depletion of flows, in DNRBV, have occurred in recent years. The typical drought years are 1977, 1987, 1998 and more recently are 2004, 2005, 2007 and 2010 [3].

[redacted] AREAS WITH DIFFERENT DROUGHT INTENSITY [3]

Intensity	Areas	Ratio between evaporation and rainfall (times)
Severe	South Central Coastal region	9.4-11.3
High	Xuan Loc, Phuoc Long, Tay Ninh, Bien Hoa	3.7-5.9
Average	Bao Loc, Lien Khuong, Da Lat	0.8-1.6

The above scenarios of ECEs show the increasing trend of rainfall and the decrease of drought day numbers, especially in dry months. Therefore, drought would reduce in the future. However, previous studies have alerted about the serious shortage of rainfall during El Nino years [2]. Moreover, it is the increases of TXx, TX90P and SU35 that gives the warning of socio-economic drought in the area.

C. *Impacts of ECEs on salinity intrusion*

Salinity intrusion at the downstream of DNRBV is highly sensitive to the exploitation of water resources in both upstream and downstream and the in-situ rainfall conditions in the basin, of which, changes of the seasonal discharge from upstream is the key factor affecting salinity boundaries in river branches. The areas which are frequently affected by salinity in dry seasons include the coastal districts of Nha Be, Binh Chanh and Thu Duc (Ho Chi Minh City), Can Giuoc, Ben Luc (Long An Province), Long Thanh (Dong Nai Province) and Chau Thanh (Ba Ria-Vung Tau Province). Despite of upward trend of rainfall in the basin, salinity intrusion might be more severe in the downstream areas due to sea level rise and in particular during El Nino years when the depletion of river flow is especially serious.

V. Conclusion

In the paper, the authors project the development of ECEs affecting water resources in the middle and the end of the 21st Century in DNRBV using climate model region CCAM dynamically downscaled from five global climate models corresponding to two climate change scenarios RCP8.5 and RCP4.5. The findings show that TXx and TNn increase throughout the 21st Century compared to the based period at all representatives stations, especially at Vung Tau station. TX90P and SU35 increase considerably at stations which have relatively high average temperature, typically, at Dong Phu station. Meanwhile the increase level is less at stations with relatively low average temperature. TN90P increases quite evenly across all stations. Regarding extreme rainfall, Rx1day and Rx3day tend to increase at all stations of which the increase in the middle is greater than in the end of the century. For Rx5day, apart from Bao Loc and Phan Rang stations with unclear trends, the other stations are likely to increase. The paper also discussed the impacts of ECEs on water resources such as floods, drought and salinity intrusion. The paper is a foundation for the further researches of the impacts of ECEs on water resources in DNRBV. It aims to support policy decision makers, scientific researchers and community at different levels to timely access and process essential information and data so that strategic orientation, appropriate solution, resources allocation and coordination can be established for local socio-economic development plans as well as appropriate Climate change adaptation measures.

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