QUANTIFYING THE RISK OF CLIMATE CHANGE TO WATER RESOURCES IN THE VU GIA - THU BON RIVER BASIN, CENTRAL VIET NAM

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Abstract: *Climate change is posing serious threat on many different aspects of lives, espcially water resource. Vu Gia - Thu Bon is one of the largest river basins located in the central region of Viet Nam, which is ranked as one of the areas severely affected by climate change. This study aims to assess the level of risk to surface water resources in Vu Gia - Thu Bon river basin in the context of climate change in 03 time slices: The baseline period 1986 - 2005 and the two future periods 2016 - 2035 and 2046 - 2065 under two scenarios RCP4.5 and RCP8.5 using IPCC approach. The results show that the level of risk to surface water resources in both periods of the two scenarios RCP4.5 and RCP8.5 is medium. In which, the Hazard index is at a high level; the Exposure is low; and the Vulnerability is at a medium level. Moreover, the indexes in both future periods of the two scenarios RCP4.5 and RCP8.5 are larger compared to the baseline period. These results are expected to contribute to the basis for decision-making and timely response solutions for relevant sectors and localities in the Vu Gia - Thu Bon river basin.*

Keywords: *Risk, surface water resources, vulnerable, scenarios.*

1. Introduction

Climate change (CC) is an increasing challenge to the socio-economic development of Viet Nam - the country is ranked to be amongst the most prone countries to natural disasters. Among others, water resource is most vulnerable to the changing climate through its impacts on the quantity, quality and availability due to its close connection with temperatures and rainfall.

Vu Gia - Thu Bon river basin (VG-TB) is located in the east of Nam Truong Son mountain range stretching from 14°57'10'' to 16°3'50'' of North latitude, 107°12'50'' to 108°44'20'' of East longitude. VG-TB is one of the four largest river in Central of Viet Nam. This system originates from Kon Tum province, flows through Quang Nam province, Da Nang city before emptying into the East Sea at Cua Dai and Cua Han. Da Nang city and Quang Nam province are located in the central economic region charactering by complex and strongly divided topographies.

Quang Nam has 3 types of topography, ecological landscape: The high mountain in the west, the midland in the middle and the coastal plains in the south. In consequence, the annual flow of VG-TB is largely different. It is less than 30.0 l/s.km² in the coastal plain and over 100.0 l/s.km² in the upper Thu Bon river. The average annual flow in many years is about 20.4 km³ which makes up approximately 2.4 % of the total annual flow of rivers and streams in Viet Nam.

The flow of VG-TB in Quang Nam province is distributed unevenly during the year. The flow volume in 3 months (October, November and December) of flood season comprises about 65 - 75% of annual flow. Meanwhile, in the dry seasons (9 months) begining from January to September, the flow volume only accounts for about 30 - 45%. The monthly average flow distribution of the year has two peaks: The main peak appears in November and the other

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appears in May due to Grain Buds rain (caused by cloudburst in the period of grain full at the end of May every year). The flow volume in November is the largest. The lowest flow occurs from February to May or from March to May depending on whether there is a Grain Buds flood, the flow volume of 3 months make up only 5 - 10% volume of the years.

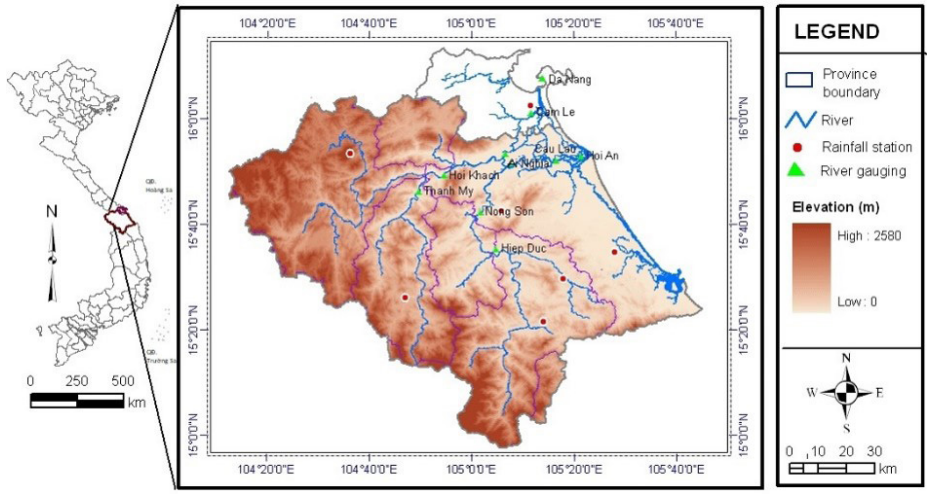


Figure 1. Topographic map of Vu Gia - Thu Bon river basin

2. Research methods and Materials

2.1. Research methods

The risks of surface water resources induced by climate change is assessed by using a 5 step framework. Detail description of this framework is presented as follows:

1. Determine the indicator

According to the IPCC report [3], Risk components include Hazard, Exposure and Vulnerability (IPCC, 2014).

- The Hazard Index (H) comprises temperature, number of hot days, precipitation and number of days of heavy rain;

- The Exposure Index (E) consists of water source, population access to the water source and production types using surface water;

- The Vulnerability Index (V) is determined as the weighted average of the parameters of Sensitivity (S) and Adaptability (AC) [1].

$$V = \frac{1}{2}[S + (1 - AC)]$$

In there:

+ The Sensitivity Index (*S*) contains the number of surface water sources, demand for water in daily life and economic sectors;

+ The Adaptability Index (*AC*) invovles reservoir systems, weirs - salinity prevention dams and pumping stations.

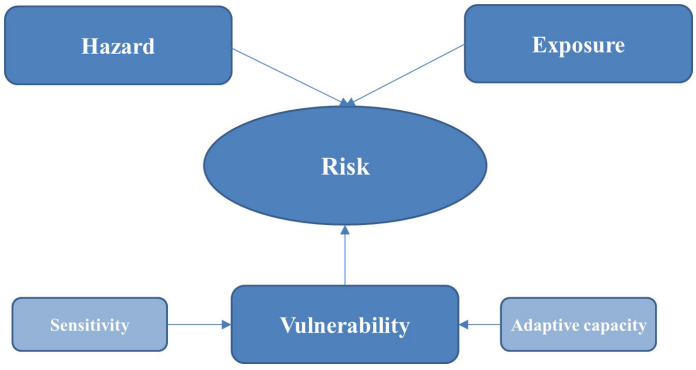


Figure 2. The diagram that makes up the risk component

2. Normalize the variables

- If the component factor is positively correlated with the main factor, normalize according to the formula:

Xij = (Xij - MinXij)/(MaxXij - MinXij)

- If the component factor is negatively correlated with the main factor, normalize according to the formula:

Xij = (MaxXij - Xij)/(MaxXij - MinXij)

3. Determine the weight

The weight Wj is determined by the Iyengar-Sudarshan method:

$$Wj = \frac{c}{\sqrt{Dxij}}$$

In there:

The constant c is determined by the formula:

$$c = 1/\left[\sum_{i=1}^{m}\left(\frac{1}{\sqrt{Dxij}}\right)\right]$$

The variance Dxij is determined by the formula:

$$Dxij = \frac{\sum_{i=1}^{M}(Xij - \overline{xij})^2}{M-1}$$

4. Calculate the value of the index

After performing steps 1, 2 and 3, the values of the main indexes (H, E, S, AC) are determined by the weighted average of the component index values.

5. Determining the risk index and risk thresholding

The Risk Index is determined by the formula:

R (risk) = 1/3 [H(Hazard) + (E(Exposure) + V(Vulnerability)]

The level of risk for each region is assessed as follows [1], if:

0 < Risk ≤ 0.2 : Very low level of risk

0.2 < Risk ≤ 0.4 : Low level of risk

0.4 < Risk ≤ 0.6 : Average level of risk

0.6 < Risk ≤ 0.8 : High level of risk

0.8 < Risk ≤ 1 : Very high level of risk

2.2. Materials

- Hydro and Meteorological data: The report uses evaporation data, temperature data and rainfall data from 3 meteorological stations (Da Nang, Tra My and Tam Ky); Rain data from 20 rain gauge stations (Thanh My, Nong Son, Da Nang, Ai Nghia, Cau Lau, Giao Thuy, Hoi An, Hoi Khach, Kham Duc, Tam Ky, Tien Phuoc, Tra My, Trao (Hien), Cam Le, Thang Binh, Hiep Duc, Hoa Phu, Hoa Bac, Xuan Binh and Nui Thanh); and discharge data at 2 stations Nong Son and Thanh My in the period 1986 - 2005 and 2 periods 2016 - 2035 and 2046 - 2065 of 2 scenarios RCP4.5 and RCP8.5 [3].

- Socio-economic data: Annual socio-economic reports of Quang Nam province and Da Nang city have been used to assess the level of risk surface water resources in the study area.

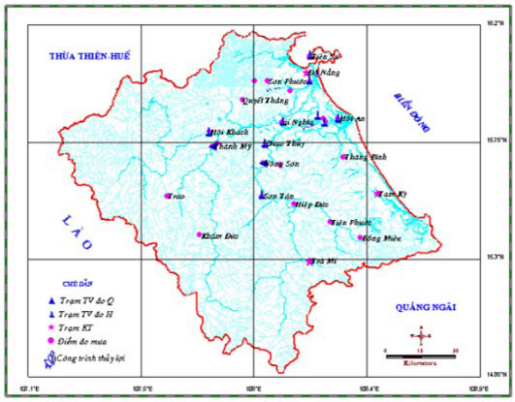


Figure 3. Map of hydrometeorological station network in Vu Gia - Thu Bon

3. Results and discussion

3.1. The result of calculating the value of the Hazard and Exposure indexes index

Values of Hazard to surface water resources of VG-TB in the period 1986 - 2005 and in the two periods 2016-2035 and 2046-2065 of the two scenarios RCP4.5 and RCP8.5 are high, have values respectively 0.700; 0.703, 0.699, 0.706 and 0.706. In which, the value of Hazard in the period 2016-2035 under the RCP4.5 scenario and the two periods 2016 - 2035 and 2046 - 2065 in the RCP8.5 scenario increased compared to the 1986 - 2005 period, with an increase of 0.310%; 0.642% and 0.616%, respectively. The period 2046 - 2065 of the scenario RCP4.5 decreased again compared to the period 1986 - 2005 with a decrease of 0.071% (Table 1 and Figure 4).

Values of the exposure for surface water resources in VG-TB in the period 1986 - 2005 and the two periods 2016 - 2035 and 2046 - 2065 of the two scenarios RCP4.5 and RCP8.5 are low, respectively 0.183; 0.187, 0.185, 0.187 and 0.185. In which, Exposure values for the two periods 2016 - 2035 and 2046 - 2065 for both scenarios RCP4.5 and RCP8.5 increased compared to the period 1986-2005, with an increase of 0.083%, 0.172%, 0.083% and 0.172%, respectively (Table 1 and Figure 5).

Table 1. Results of the calculation of the Hazard and Exposure indexes value

District/city	Values of Hazard index					Values of Exposure index				
	1986 - 2005	RCP4.5		RCP8.5		1986 - 2005	RCP4.5		RCP8.5	
		2016 - 2035	2046 - 2065	2016 - 2035	2046 - 2065		2016 - 2035	2046 - 2065	2016 - 2035	2046 - 2065
Hoa Vang (Da Nang)	0.869	0.869	0.871	0.880	0.880	0.525	0.525	0.525	0.525	0.525
Tam Ky	0.767	0.777	0.763	0.770	0.769	0.481	0.448	0.375	0.448	0.375
Hoi An	0.869	0.869	0.871	0.880	0.880	0.333	0.339	0.333	0.339	0.333
Tay Giang	0.869	0.869	0.871	0.880	0.880	0.039	0.039	0.040	0.039	0.040
Dong Giang	0.869	0.869	0.871	0.880	0.880	0.050	0.048	0.048	0.048	0.048
Dai Loc	0.869	0.869	0.871	0.880	0.880	0.100	0.108	0.110	0.108	0.110
Dien Ban	0.869	0.869	0.871	0.880	0.880	0.347	0.399	0.406	0.399	0.406
Duy Xuyen	0.869	0.869	0.871	0.880	0.880	0.182	0.180	0.177	0.180	0.177
Que Son	0.818	0.823	0.817	0.825	0.825	0.173	0.175	0.165	0.175	0.165
Nam Giang	0.573	0.577	0.572	0.578	0.577	0.370	0.371	0.375	0.371	0.375
Phuoc Son	0.573	0.577	0.572	0.578	0.577	0.033	0.034	0.036	0.034	0.036
Hiep Duc	0.573	0.577	0.572	0.578	0.577	0.048	0.050	0.054	0.050	0.054
Thang Binh	0.818	0.823	0.817	0.825	0.825	0.110	0.115	0.116	0.115	0.116
Tiên Phuoc	0.573	0.577	0.572	0.578	0.577	0.132	0.139	0.154	0.139	0.154
Bac Tra My	0.083	0.083	0.083	0.083	0.083	0.064	0.063	0.063	0.063	0.063
Nam Tra My	0.083	0.083	0.083	0.083	0.083	0.050	0.050	0.050	0.050	0.050
Nui Thanh	0.767	0.777	0.763	0.770	0.769	0.227	0.244	0.244	0.244	0.244
Phu Ninh	0.767	0.777	0.763	0.770	0.769	0.156	0.163	0.166	0.163	0.166
Nong Son	0.818	0.823	0.817	0.825	0.825	0.065	0.065	0.069	0.065	0.069
Average	**0.700**	**0.703**	**0.699**	**0.706**	**0.706**	**0.183**	**0.187**	**0.185**	**0.187**	**0.185**

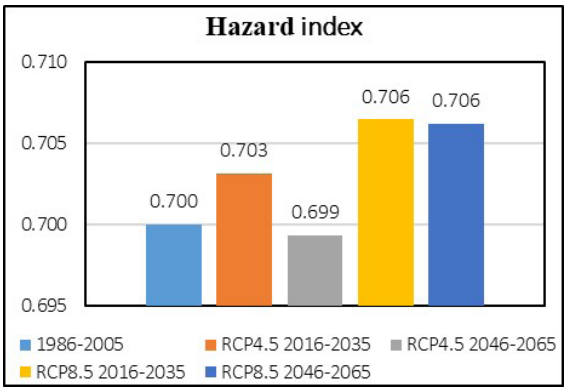


Figure 4. Hazard Value for Surface Water Resources in Vu Gia - Thu Bon

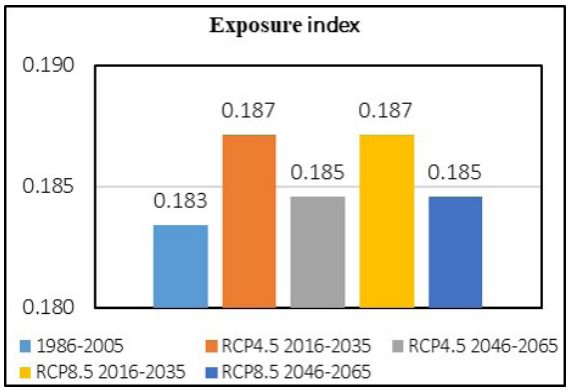


Figure 5. Exposure Values to Surface Water Resources in Vu Gia - Thu Bon

3.2. Sensitivity and Adaptability indexes value calculation results

The Sensitivity indexes for surface water resources in VG-TB in the period 1986 - 2005 and the two periods 2016 - 2035 and 2046 - 2065 of the two scenarios RCP4.5 and RCP8.5 are low at 0.125; 0.123, 0.144, 0.149 and 0.152, respectively. In which, the values of Sensitivity in the periods 2046 - 2065 for both scenarios RCP4.5 and the two periods 2016 - 2035 and 2046 - 2065 for both scenarios RCP8.5 increased compared to the period 1986 - 2005, with an increase of 1.885%, 2.320% and 2.681% respectively; and Sensitivity values for the periods 2016 - 2035 for scenario RCP4.5 decreased compared to the period 1986 - 2005, with an increase of 0.201% (Table 2 and Figure 6).

The Adaptability indexes for surface water resources in VG-TB in the period 1986 - 2005 and the two periods 2016 - 2035 and 2046 - 2065 of the two scenarios RCP4.5 and RCP8.5 are low, with all values 0.134 (Table 2 and Figure 7).

Adaptability includes the following factors: Reservoir, Weir, Pumping Station. The baseline period uses updated data to 2021. Since there is no data for future planning, in the periods 2016 - 2035, 2046 - 2065 of climate change scenarios, the data used will not change compared to that of the climate change scenarios with the baseline period.

Table 2. Results of Calculation of Sensitivity and Adaptability Indexes Values

District/city	Values of Hazard index					Values of Exposure index				
	1986 - 2005	RCP4.5		RCP8.5		1986 - 2005	RCP4.5		RCP8.5	
		2016 - 2035	2046 - 2065	2016 - 2035	2046 - 2065		2016 - 2035	2046 - 2065	2016 - 2035	2046 - 2065
Hoa Vang (Da Nang)	0.921	0.899	0.955	1.000	0.979	0.369	0.369	0.369	0.369	0.369
Tam Ky	0.050	0.050	0.168	0.131	0.168	0.033	0.033	0.033	0.033	0.033
Hoi An	0.137	0.142	0.184	0.272	0.252	0.052	0.052	0.052	0.052	0.052
Tay Giang	0.010	0.014	0.097	0.014	0.014	0.090	0.090	0.090	0.090	0.090
Dong Giang	0.018	0.034	0.105	0.023	0.022	0.151	0.151	0.151	0.151	0.151
Dai Loc	0.224	0.207	0.253	0.257	0.236	0.135	0.135	0.135	0.135	0.135
Dien Ban	0.183	0.155	0.183	0.187	0.167	0.318	0.318	0.318	0.318	0.318
Duy Xuyen	0.119	0.101	0.169	0.172	0.152	0.235	0.235	0.235	0.235	0.235
Que Son	0.084	0.072	0.121	0.117	0.154	0.099	0.099	0.099	0.099	0.099
Nam Giang	0.055	0.079	0.143	0.060	0.060	0.116	0.116	0.116	0.116	0.116

District/city	Values of Hazard index					Values of Exposure index				
	1986 - 2005	RCP4.5		RCP8.5		1986 - 2005	RCP4.5		RCP8.5	
		2016 - 2035	2046 - 2065	2016 - 2035	2046 - 2065		2016 - 2035	2046 - 2065	2016 - 2035	2046 - 2065
Phuoc Son	0.022	0.028	0.018	0.019	0.019	0.046	0.046	0.046	0.046	0.046
Hiep Duc	0.063	0.039	0.029	0.030	0.030	0.111	0.111	0.111	0.111	0.111
Thang Binh	0.072	0.173	0.067	0.147	0.173	0.037	0.037	0.037	0.037	0.037
Tiên Phuoc	0.072	0.045	0.028	0.029	0.028	0.220	0.220	0.220	0.220	0.220
Bac Tra My	0.048	0.026	0.016	0.017	0.016	0.148	0.148	0.148	0.148	0.148
Nam Tra My	0.023	0.014	0.005	0.006	0.006	0.041	0.041	0.041	0.041	0.041
Nui Thanh	0.112	0.113	0.083	0.153	0.190	0.041	0.041	0.041	0.041	0.041
Phu Ninh	0.051	0.067	0.042	0.111	0.148	0.298	0.298	0.298	0.298	0.298
Nong Son	0.120	0.087	0.077	0.079	0.078	0.003	0.003	0.003	0.003	0.003
Average	**0.125**	**0.123**	**0.144**	**0.149**	**0.152**	**0.134**	**0.134**	**0.134**	**0.134**	**0.134**

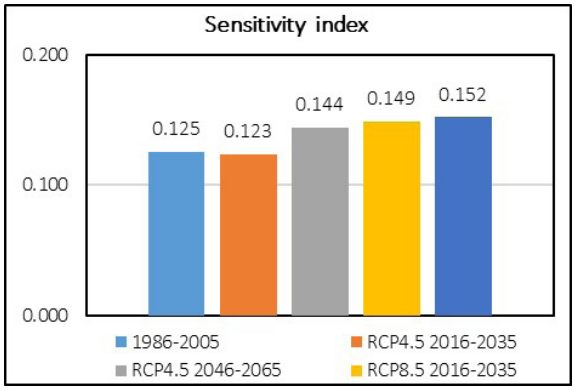


Figure 6. Sensitivity Value for Surface Water Resources in Vu Gia - Thu Bon

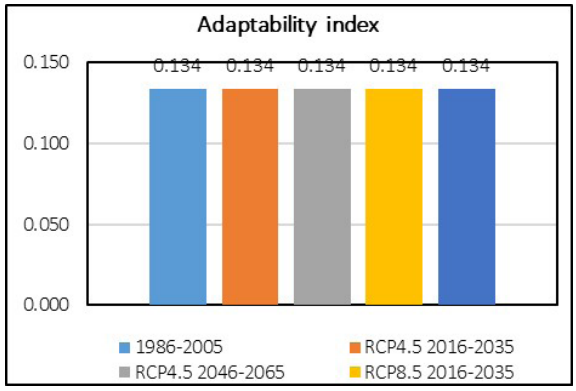


Figure 7. Adaptability Values to Surface Water Resources in Vu Gia - Thu Bon

3.3. Vulnerability and Risk indexes value calculation results

Vulnerability indexes to surface water resources in VG-TB in the period 1986 - 2005 and the two periods 2016 - 2035 and 2046 - 2065 of the two scenarios RCP4.5 and RCP8.5 are at average level, whose values are respectively: 0.496; 0.495, 0.505, 0.507 and 0.509. In which, the index of Vulnerability in the period 2016 - 2035 under the RCP4.5 scenario and the two periods 2016 - 2035 and 2046 - 2065 in the RCP8.5 scenario increase when comparing to the 1986 - 2005 period, with an increase of 0.943%; 1.160% and 1.340%, respectively. The period 2046 - 2065 of the scenario RCP4.5 decreased again compared to the period 1986 - 2005 with a decrease of 0.100%.

Risk indexes to surface water resources in VG-TB in the period 1986 - 2005 and the two periods 2016 - 2035 and 2046 - 2065 of the two scenarios RCP4.5 and RCP8.5 are at medium. Whose values are 0.460; 0.462, 0.463, 0.467 and 0.467, respectively. In which, the level of risk for the two periods 2016 - 2035 and 2046 - 065 of both scenarios RCP4.5 and RCP8.5 increased when comparing to the period 1986 - 2005, with an increase of 0.098%, 0.348%, 0.629% and 0.709% respectively (Table 3 and Figure 9).

The level of risk to surface water resources in VG-TB in the period 1986 - 2005 and the two periods 2016 - 2035 and 2046 - 2065 of the two scenarios RCP4.5 and RCP8.5 is shown in Fig.10.

Table 3. Results of Vulnerability and Risk Index Calculation

District/city	Values of Hazard index					Values of Exposure index				
	1986 - 2005	RCP4.5		RCP8.5		1986 - 2005	RCP4.5		RCP8.5	
		2016 - 2035	2046 - 2065	2016 - 2035	2046 - 2065		2016 - 2035	2046 - 2065	2016 - 2035	2046 - 2065
Hoa Vang (Da Nang)	0.776	0.765	0.793	0.816	0.805	0.694	0.684	0.687	0.704	0.694
Tam Ky	0.508	0.508	0.567	0.549	0.567	0.491	0.487	0.494	0.498	0.496
Hoi An	0.543	0.545	0.566	0.610	0.600	0.511	0.512	0.519	0.537	0.534
Tay Giang	0.460	0.462	0.503	0.462	0.462	0.455	0.456	0.471	0.460	0.460
Dong Giang	0.434	0.441	0.477	0.436	0.436	0.453	0.453	0.465	0.455	0.454
Dai Loc	0.544	0.536	0.559	0.561	0.551	0.533	0.533	0.543	0.545	0.543
Dien Ban	0.433	0.418	0.432	0.435	0.424	0.548	0.548	0.552	0.557	0.552
Duy Xuyen	0.442	0.433	0.467	0.469	0.459	0.521	0.514	0.520	0.530	0.521
Que Son	0.493	0.487	0.511	0.509	0.528	0.498	0.495	0.495	0.503	0.504
Nam Giang	0.469	0.481	0.513	0.472	0.472	0.454	0.458	0.466	0.456	0.454
Phuoc Son	0.488	0.491	0.486	0.487	0.487	0.372	0.374	0.373	0.373	0.375
Hiep Duc	0.476	0.464	0.459	0.460	0.460	0.369	0.367	0.367	0.366	0.369
Thang Binh	0.518	0.568	0.515	0.555	0.568	0.509	0.528	0.509	0.524	0.529
Tiên Phuoc	0.426	0.413	0.404	0.404	0.404	0.416	0.413	0.409	0.411	0.411
Bac Tra My	0.450	0.439	0.434	0.434	0.434	0.212	0.207	0.204	0.206	0.204
Nam Tra My	0.491	0.486	0.482	0.483	0.482	0.213	0.211	0.210	0.210	0.210
Nui Thanh	0.536	0.536	0.521	0.556	0.574	0.553	0.556	0.547	0.561	0.567
Phu Ninh	0.377	0.385	0.372	0.407	0.425	0.437	0.443	0.433	0.448	0.452
Nong Son	0.558	0.542	0.537	0.538	0.538	0.493	0.488	0.484	0.487	0.487
Average	**0.496**	**0.495**	**0.505**	**0.507**	**0.509**	**0.460**	**0.459**	**0.460**	**0.465**	**0.464**

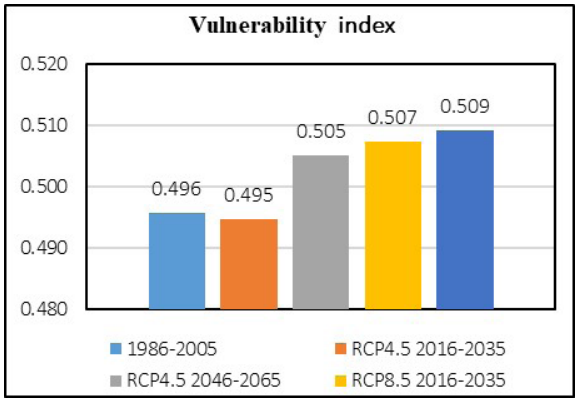


Figure 8. Vulnerability Value for Surface Water Resources in Vu Gia - Thu Bon

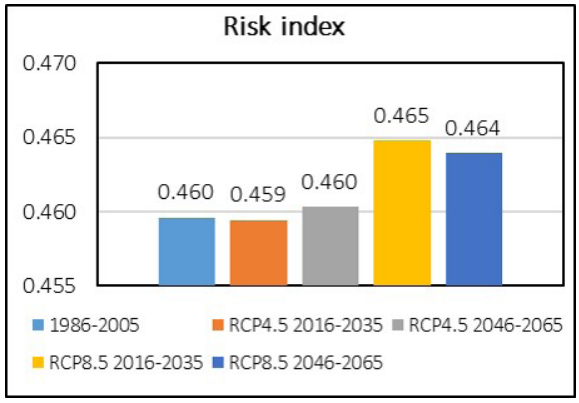
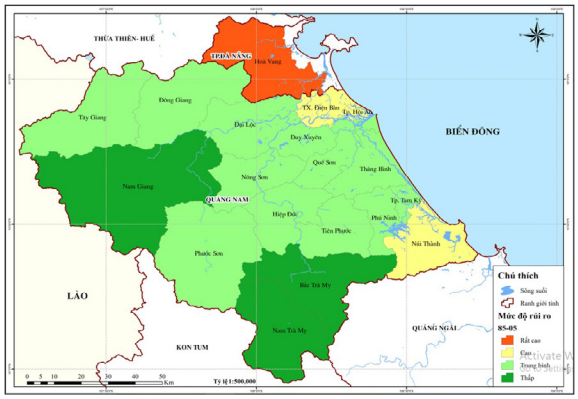
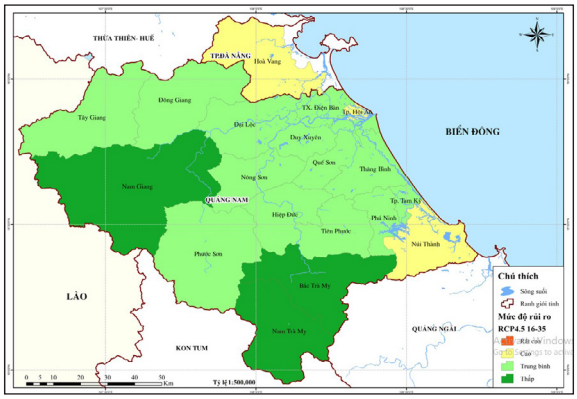


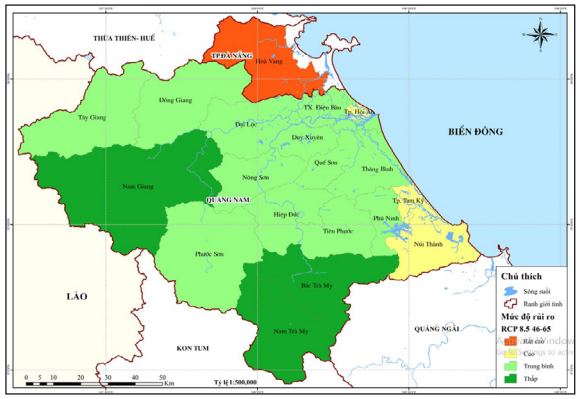
Figure 9. Risk Values to Surface Water Resources in Vu Gia - Thu Bon



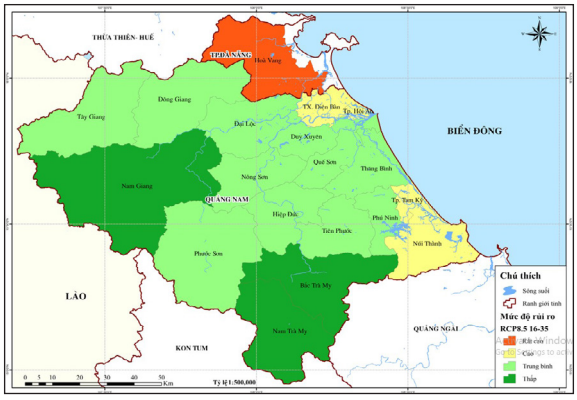
Base 1986 - 2005



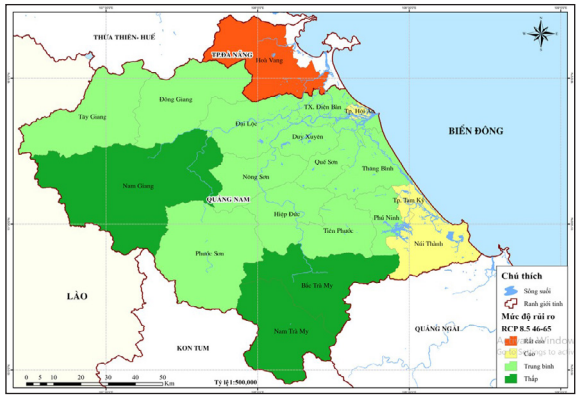
2016 - 2035 (RCP4.5)



2046 - 2065 (RCP4.5)



2016 - 2035 (RCP8.5)



2046 - 2065 (RCP8.5)

Figure 10. Risk level map for surface water resources in Vu Gia - Thu Bon

The results show that the most of the factors of Hazard, Exposure, Vulnerability and Risk for surface water resources in VG-TB in two periods 2016 - 2035, 2046 - 2065 of both scenarios RCP4.5 and RCP8.5 mostly increase compared to baseline period 1986 - 2005. Only the Vulnerability and Risk indexes in the period 2046 - 2065 of the scenario RCP4.5 tend to decrease compared to the baseline period 1986 - 2005.

Results show that there is not much change of indexes between the periods 2016 - 2035, 2046 - 2065 of the two climate change scenarios. A possible reason is that after normalization, the indexes are returned to dimensionless form and have values from 0 to 1. The initial values of the indexes have

many changes due to the impact of climate change, however, values after normalization do not change or change insignificantly between periods. As can be seen, the standardization has blurred the impact of climate change. For example: Total annual flow in Hoi An city in the base period 1986 - 2005 is 16,585.2 10^6 m^3; under the RCP4.5 scenario, the period 2016 - 2035 is 31,102.5 10^6 m^3 (increasing 14,517.4 106 m^2 compared to the baseline period), the period 2046 - 2065 is 33,252.7 10^6 m^3 (increasing 16,667.6 10^6 m^3 compared to the baseline period); under the RCP8.5 scenario, the period 2016 - 2035 is 30,689.7 10^6 m^3 (an increase of 14,104.6 10^6 m^3 compared to the baseline period), in the period 2046 - 2065 is 32,374.6 10^6 m^3 (an increase of 15,789.5 10^6 m^3 compared to the baseline period). The above results show that climate change has a strong impact on the flow.

4. Conclusions

The level of risk to surface water resources in VG-TB in the period 1986 - 2005 and the two periods 2016 - 2035, 2046 - 2065 under 2 scenarios RCP4.5 and RCP8.5 are at a medium level with values of 0.460, 0.462; 0.463; 0.467 and 0.467, respectively. The Hazard Index is high with values of: 0.700, 0.703; 0.699; 0.706 and 0.706 respectively. The Exposure Index is low with values of 0.183; 0.187; 0.185; 0.187 and 0.185. The Vulnerability Index is medium with values respectively: 0.496; 0.495; 0.505; 0.507; 0.509.

All in all, Risk and Hazard, Exposure and Vulnerability indicators in VG-TB in two periods 2016 - 2035 and 2046 - 2065 of both scenarios RCP4.5 and RCP8.5 are larger than the ones in the period 1986 - 2005 indicating the more challenging of the area under the future climate change.

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