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*Research Article*

# Impact of climate change on seasonal distribution of flows in Ca basin, Central Viet Nam

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**Abstract:** Climate change has been impacting both natural and human resources greatly. Flow in river basins is subjected to strongly affect due to its direct relevance to climatic factors. Many changes in the distribution of runoff on river basins throughout the year due to the impact of climate change (CC) have been observed. In some areas, the flood season tends to shift gradually towards the end of the year, making the flood season appear later than before, but there are also areas where the flood season occurs earlier. The paper specifically analyzes changes in the distribution of flood season in a year under the impact of climate change in some areas in the Ca River basin, central Viet Nam.

**Keywords:** Climate change; River flow; Flow distribution; Ca River basin.

## 1. Introduction

At present, climate change continues to be one of the most concerning global issues, along with the coronavirus pandemic [1]. Climate warming will alter several water cycle components, such as varying the pattern and intensity of precipitation, increasing water vapor and evaporation, and changing runoff [2]. Particularly, climate change is projected to exacerbate the change of flow regimes in Vietnam significantly. River flow varies over space and time therefore knowledge about changing river flow regimes is paramount for assessing climate change risks related to freshwater. Estimation of changes in seasonality, inter-annual variability, statistical low and high flows, and floods and droughts is required to understand the impact of climate change on humans and freshwater ecosystems [3]. Climate change impact studies for river basins mostly focus on changes of river discharge and aspects of its temporal variability, in particular seasonality [4–9]. In Vietnam, research studies on impact of climate change on river flows focusing on changes of flow magnitude and occurence are prominent [10]. Studies on the impact of climate change on river flow regimes considering both spatial and temporal scales are still limited. This study looks at the changes in the timing of flood season in a year under the impact of climate change in the Ca River basin which is located in the central Vietnam and is subjected to the greatly vulnerable due to climate change. We wanted to find out how significant change of the flood flow regime in terms of spatial and temporal scales under the impact of climate change. The state-of-the-art modelling chain method was used to translate climate scenarios (as developed by Ministry of Natural Resources and Environment [11]) into scenarios of flow regime indicators including flood flow regime and of shifts between perennial and intermittent flood flow regimes.

## 2. Materials and Methods

### *2.1 Description of study site*

Ca River is a transboundary river, originating from a high mountain range in Xiengkhuang in Laos with a peak of 2.000 m, flowing northwest–southeast into Vietnam, pouring into the sea at the Hoi River mouth. The Ca River is about 514 km long, of which the part flowing in the territory of Vietnam is 360 km long. Ca River basin is the largest river system in the North Central region, Ca River system is in the coordinate range 103°14'–106°10' east longitude, 17°50'–20°50' north latitude, stretching about 350 km in the northwest–southeast direction, 89 km wide; adjacent to the Ma river system to the north, the Mekong River system to the west, the Gianh river to the south and the Gulf of Tonkin to the east. The total catchment area is 27.200 km$^2$, of which the part of the basin lying in Vietnam has an area of 17.730 km$^2$, accounting for 65.2% of the entire basin area, located in the coordinates 103°45'20"–105°15'20" east longitude, 18°15'00"–20°10'30" north latitude, covers most of Nghe An Province, Ha Tinh Province and part of Nhu Xuan district, Thanh Hoa Province (Figure 1).

Ca River basin is divided into 3 separate regions including the upstream of Ca River in the west, the Hieu River basin in the north, and the La River basin in the south. Upstream of La River has 2 main river branches namely Ngan Sau and Ngan Pho. In different regions, the distribution of the flood season months in the year also varies differently. On the upstream of Ca River, there is a flood season lasting for 5 months from July to November (represented by the Dua hydrological station), the Hieu River basin has a flood season lasting for 3 months from August to October (represented by the Nghia Khanh hydrological station). Ngan Sau River basin has a flood season lasting for 3 months from September to November (represented by Hoa Duyet hydrological station), Ngan Pho River basin has a flood season lasting 4 months from August to November (represented by Son Diem hydrological station). To consider the impact of climate change on the flow regime in flood season for the Ca River basin, this study will investigate the distribution of flood season at 4 hydrological stations of Dua, Nghia Khanh, Hoa Duyet and Son Diem represented for 4 regions forming the Ca River basin.

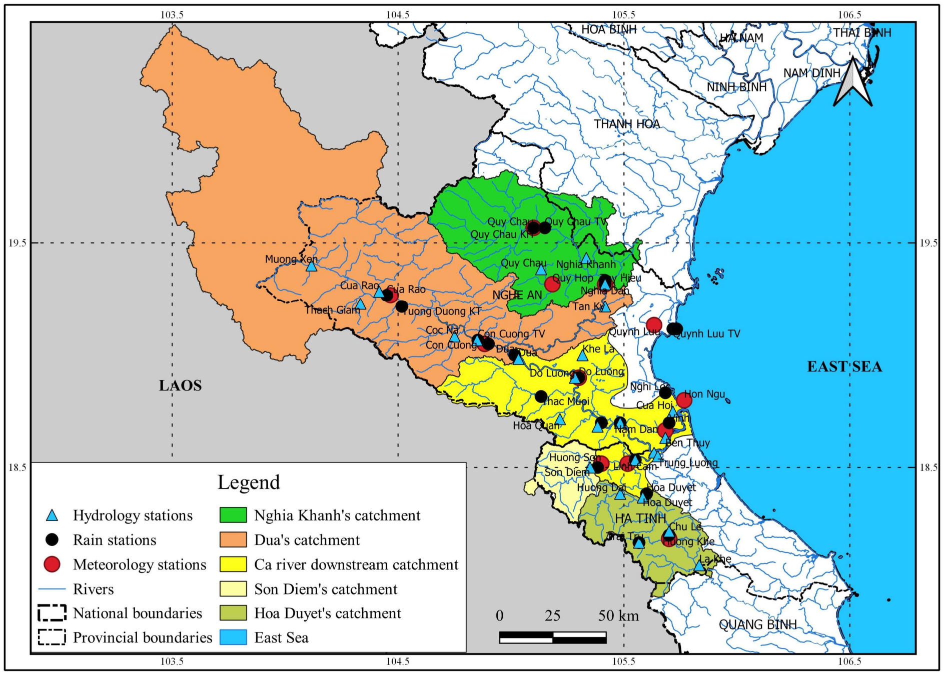

**Figure 1.** Ca River Basin.

### *2.2. Calculation Method*

The hydrological model MIKE–NAM [12] is used to simulate runoff from rain. This is the method commonly used to calculate runoff for regions with tropical climatic characteristics and has been widely applied for many river basins in Vietnam. The statistical analysis method is used to analyze the impact of climate change on the change of months in the flood season in the year. The Penman–Monteith formula [13] is used to calculate the potential evaporation amount at the meteorological stations as follows:

$$ET_0 = 1 + \frac{0,408\Delta\left(R_n - G\right) + \gamma\dfrac{900}{T+273}u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0,34u_2\right)} \tag{2}$$

where $ET_o$ is the reference crop evapotranspiration (mm/day); $R_n$ is net radiation on plant surface (MJ/m$^2$/day); G is the heat flux density of the soil (MJ/m$^2$/day); T is the daily average temperature at an altitude of 2 m ($^o$C); $u_2$ is the wind speed at the height of 2m (m/s); $e_s$ is the saturated steam pressure (kPa); $e_a$ is the actual steam pressure (kPa); Δ the slope of the steam pressure curve (kPa/$^o$C); γ is the moisture constant (kPa/$^o$C).

### *2.3. Data used*

– Daily observations of average, maximum, and minimum temperature in the 1986–2005 period at 6 meteorological stations on Ca River basin including Tuong Duong, Quy Chau, Tay Hieu, Do Luong, Vinh, and Huong Khe were used to calculate the amount of potential evapotranspiration as input to the MIKE–NAM model.

– Daily rainfall data in the 1986–2005 period at 14 hydrometeorological stations measuring rainfall on Ca River basin including Cua Rao, Tuong Duong, Quy Chau, Nghia Khanh, Con Cuong, Tay Hieu, Dua, Do Luong, Nam Dan, Son Diem, Hoa Duyet, Huong Khe, Linh Cam, Vinh were used as input to the MIKE–NAM model.

– Daily average water discharges in the 1986–2005 period at 2 hydrological stations of Dua, Nghia Khanh and the period 1997–2005 at 2 hydrological stations of Hoa Duyet, Son Diem were used to calibrate and validate parameters of the MIKE–NAM model.

– Daily data of average, maximum, minimum temperature, and rainfall at the stations in the period 2016–2035, 2046–2065, 2080–2099 derived from the scenarios RCP4.5 and RCP8.5 were used to calculate flow under climate change scenarios.

### *2.4. Model set up*

In this study, the MIKE–NAM model was set up for 4 sub–basins including Dua, Nghia Khanh, Hoa Duyet and Son Diem. The precipitation in subbasin Dua employs data from 8 stations and the evaporation data in subbasin Dua employs from Tuong Duong station; subbasin Nghia Khanh uses precipitation data from 6 stations and evaporation data from Quy Chau station; subbasin Hoa Duyet uses rainfall data from 3 stations and evaporation data from Huong Khe station; subbasin Son Diem using rainfall data from Son Diem station and evaporation data from Vinh station (Table 1). A map of subbasins and weight of every rain gauge for 4 subbasins are shown in Figure 2 and Table 1.

**Table 1.** Weight of rain gauges estimated using Theissen polygon.

| | **Rain gauge** | **Subbasin Dua** | **Subbasin Nghĩa Khanh** | **Subbasin Hòa Duyet** | **Subbasin Son Diem** |
|---|---|---|---|---|---|
| Area (km$^2$) | | 20,800 | 4,024 | 1,880 | 790 |
| Station weight | Quy Chau | 0.15 | 0.72 | | |
| | Cua Rao | 0.48 | 0.03 | | |

| **Rain gauge** | **Subbasin Dua** | **Subbasin Nghĩa Khanh** | **Subbasin Hòa Duyet** | **Subbasin Son Diem** |
|---|---|---|---|---|
| Tuong Duong | 0.17 | | | |
| Nghia Khanh | 0.03 | 0.15 | | |
| Tay Hieu | 0.04 | 0.07 | | |
| Con Cuong | 0.09 | 0.01 | | |
| Dua | 0.03 | 0.02 | | |
| Dô Luong | 0.01 | | | |
| Son Diem | | | 0.03 | 1 |
| Hoa Duyet | | | 0.29 | |
| Huong Khe | | | 0.68 | |
| Meteorological gauge | Tuong Duong | Quy Chau | Huong Khe | Vinh |

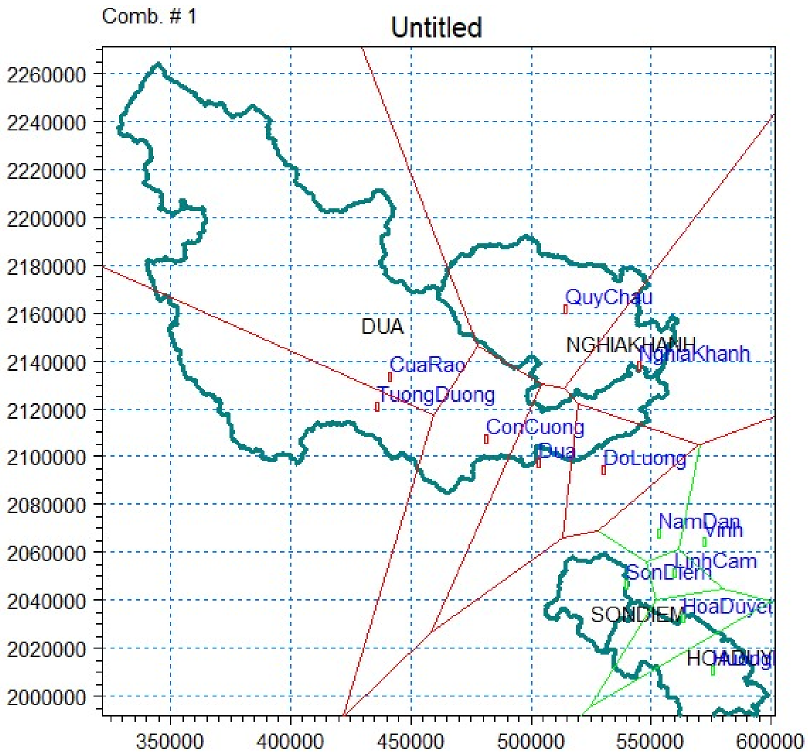

**Figure 2.** Map of subbasins.

## 3. Results and discussion

### *3.1. Calibration and validation of MIKE–NAM model parameter set*

For the catchment of the Dua and Nghia Khanh hydrological stations, the data series from 1986–1995 was used for calibration and the data series from 1996–2005 was used for verification of the parameter set of the MIKE–NAM model. The Nash index [14] is used to test the agreement between the calculated results of runoff and actual measured data.

For the basin of Hoa Duyet and Son Diem hydrological stations, the data series from 1997–2001 was used for calibration and the data series from 2002–2005 was used for verification of the MIKE model parameters.

After calibration, the study obtained the MIKE–NAM model parameters for the basin of 4 hydrological stations of Dua, Nghia Khanh, Hoa Duyet, and Son Diem (Table 2).

**Table 2.** The calibrated MIKE–NAM model parameter set for the catchments of the hydrological stations in the Ca River basin.

| No. | Model Parameters | Dua | Nghia Khanh | Hoa Duyet | Son Diem |
|---|---|---|---|---|---|
| 1 | Umax | 2.3 | 2.37 | 1.4 | 1.8 |
| 2 | Lmax | 19 | 13.5 | 19.1 | 12.8 |
| 3 | CQOF | 0.328 | 0.7 | 0.679 | 0.967 |
| 4 | CKIF | 18.95 | 8.061 | 22.76 | 5.4 |
| 5 | CK1,2 | 48.3 | 38.7 | 39 | 23 |
| 6 | TOF | 0.551 | 0.9 | 0.443 | 0.957 |
| 7 | TIF | 0.00003 | 0.000166 | 0.26 | 0.00032 |
| 8 | TG | 0 | 0.000134 | 0 | 0.000296 |
| 9 | CKBF | 2000 | 2711 | 2000 | 980.2 |

The MIKE–NAM model parameters for the basin of 4 hydrological stations, after being calibrated, were verified to check the reliability. The calculated and observed water discharge at the hydrological stations in the two periods of calibration and verification are shown from Figure 3 to Figure 10.

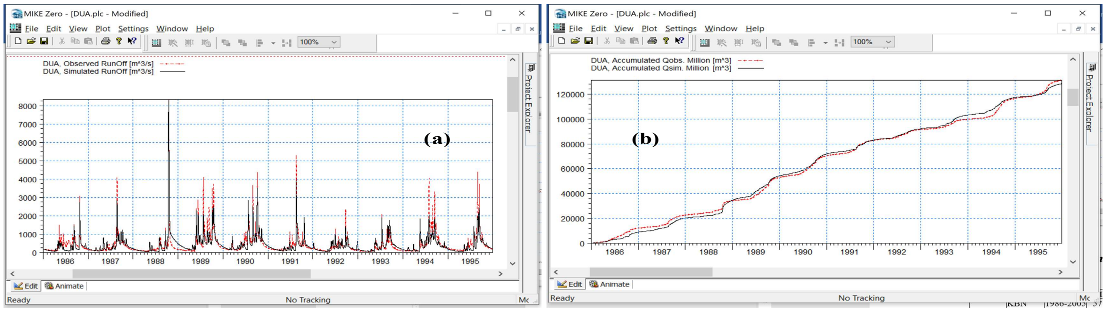

**Figure 3.** Process line (a) and accumulation line (b) of calculated and observed water discharge at Dua station in the period 1986–1995 (Calibration).

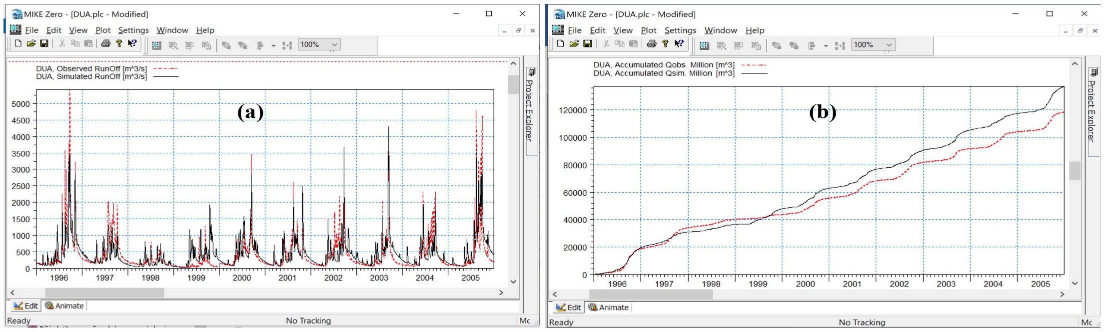

**Figure 4.** Process line (a) and accumulation line (b) of calculated and observed water discharge at Dua station in the period 1996–2005 (Verification).

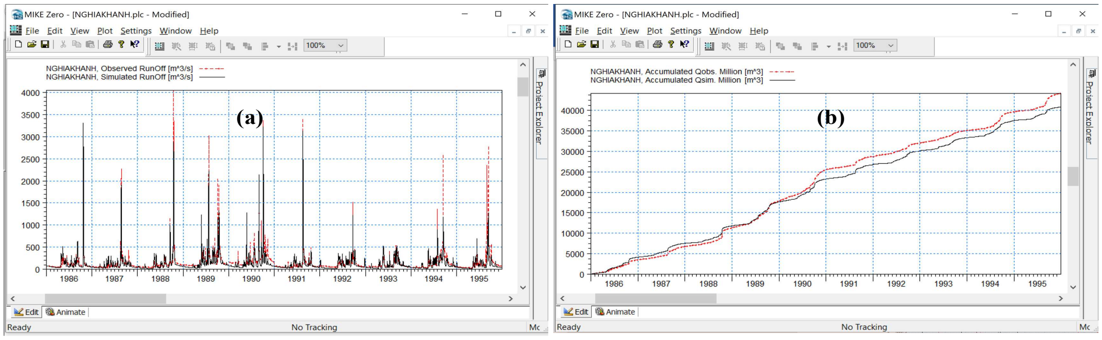

**Figure 5.** Process line (a) and accumulation line (b) of calculated and observed water discharge at Nghia Khanh station in the period 1986–1995 (Calibration).

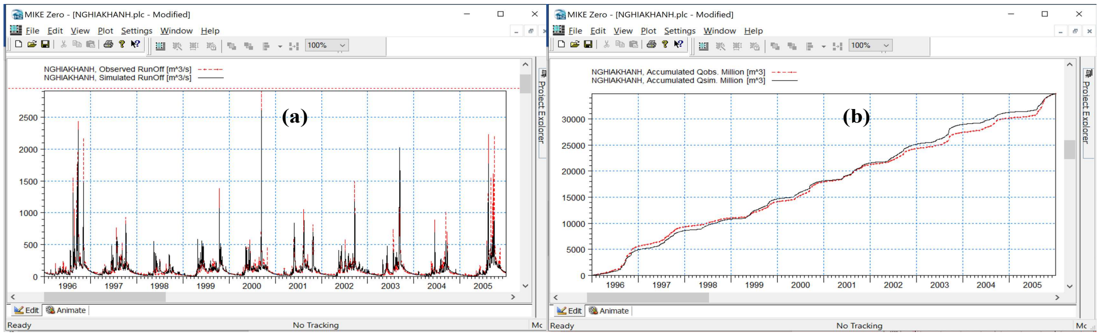

**Figure 6.** Process line (a) and accumulation line (b) of calculated and observed water discharge at Nghia Khanh station in the period 1996–2005 (Verification).

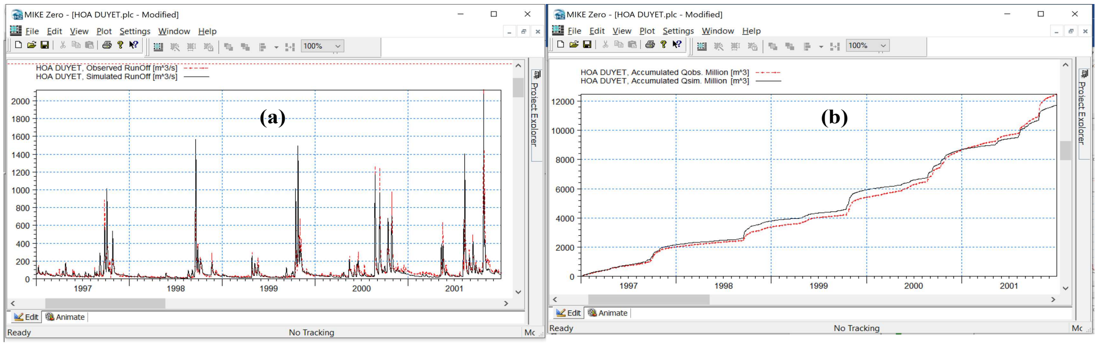

**Figure 7.** Process line (a) and accumulation line (b) of calculated and observed water discharge at Hoa Duyet station in the period 1997–2001 (Calibration).

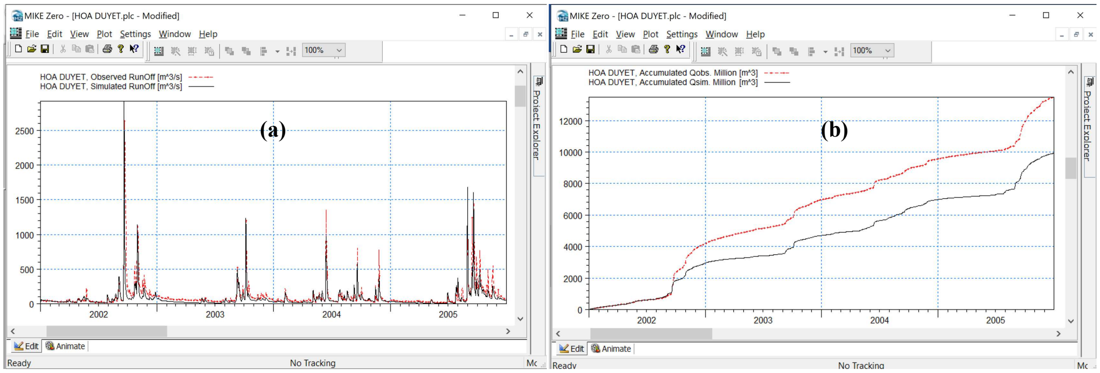

**Figure 8.** Process line (a) and accumulation line (b) of calculated and observed water discharge at Hoa Duyet station in the period 2002–2005 (Verification).

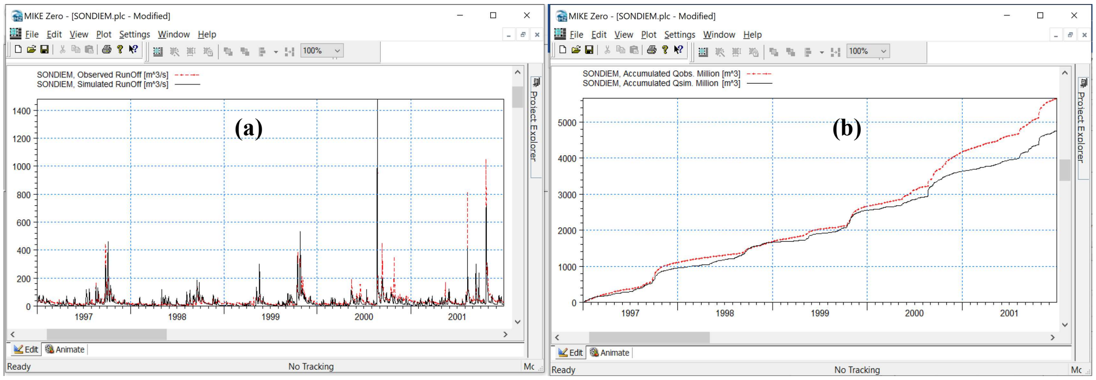

**Figure 9.** Process line (a) and accumulation line (b) of calculated and observed water discharge at Son Diem station in the period 1997–2001 (Calibration).

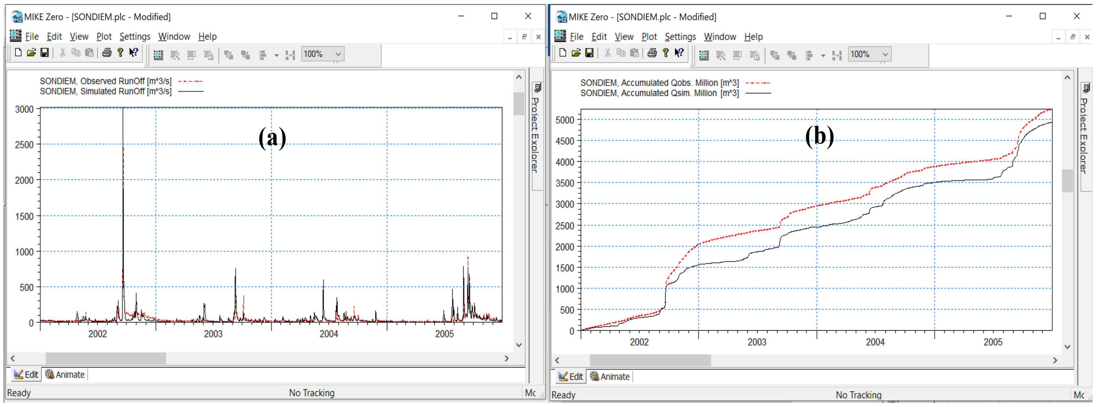

**Figure 10.** Simulated and observed hydrograph (a) and accumulated discharges (b) at Son Diem station in the period 2002–2005 (Verification).

The accuracy of the results of the runoff calculation to the hydrological stations on the Ca River basin is evaluated by Nash–Sutcliffe criteria. Evaluation results are presented in Table 3. It can be seen in the table 3, the results of runoff simulation to 10 hydrological stations on the Ca River basin by the MIKE NAM model are reliable during both calibration and verification with Nash–Sutcliffe criteria ranging from 0.72 to 0.82. Thus, the MIKE NAM model parameters after being calibrated and validated can be used to calculate runoff for different scenarios.

**Table 3.** Calibration and Verification results of MIKE–NAM model parameters.

| No. | Hydrological stations | Calibration | | Verification | |
|---|---|---|---|---|---|
| | | Period | Nash | Period | Nash |
| 1 | Dua | 1986–1995 | 0.80 | 1996–2005 | 0.76 |
| 2 | Nghia Khanh | 1986–1995 | 0.77 | 1996–2005 | 0.82 |
| 3 | Hoa Duyet | 1997–2001 | 0.82 | 2002–2005 | 0.72 |
| 4 | Son Diem | 1997–2001 | 0.76 | 2002–2005 | 0.79 |

## *3.2. Runoff calculation results under Climate change scenarios*

The MIKE–NAM model parameters after calibration and verification are used to calculate the runoff to the Dua, Nghia Khanh, Hoa Duyet, and Son Diem sub–basins for the baseline period 1986–2005 and future periods 2016–2035, 2046–2065, 2080–2099 under RCP4.5 and RCP8.5 scenarios. The results of the calculation of average monthly water discharge in the baseline period 1986–2005 and the periods 2016–2035, 2046–2065, 2080–2099 under the scenarios RCP4.5 and RCP8.5 are summarized in Table 4.

In Table 4, discharges in the baseline period are measured data at the hydrological stations; discharges in the period 2016–2035, 2046–2065, 2080–2099 under the scenarios RCP4.5 and RCP8.5 are simulated from the MIKE–NAM model. The bold runoff values are values greater than the annual mean runoff values and these are considered flood season runoff.

**Table 4.** Results of the calculation of average water discharge over time by climate change scenarios.

| Station | Scenarios | Period | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Annual Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Nghia Khanh** | Baseline | 1986–2005 | 57.6 | 51.3 | 48.1 | 49.6 | 96.1 | 120.8 | 123.1 | 208.5 | 305.9 | 251.1 | 117.3 | 69.0 | 124.9 |
| | RCP4.5 | 2016–2035 | 110.4 | 95.2 | 130.7 | 167.3 | 267.7 | 241.2 | 233.8 | 291.9 | 477.6 | 375.3 | 212.8 | 121.3 | 227.1 |
| | | 2046–2065 | 129.6 | 113.7 | 126.6 | 181.5 | 230.3 | 309.6 | 163.1 | 263.0 | 430.3 | 473.0 | 286.8 | 148.5 | 238.0 |

| Station | Scenarios | Period | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Annual Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2080–2099 | 123.6 | 112.5 | 129.8 | 178.9 | 319.0 | 237.0 | 207.0 | 334.4 | 540.9 | 518.3 | 260.7 | 138.5 | 258.4 |
| | RCP8.5 | 2016–2035 | 103.4 | 94.1 | 122.9 | 181.5 | 261.4 | 238.7 | 282.3 | 333.5 | 422.0 | 296.3 | 235.9 | 132.2 | 225.3 |
| | | 2046–2065 | 132.6 | 108.2 | 118.9 | 183.7 | 263.9 | 218.0 | 210.2 | 280.5 | 439.5 | 460.8 | 239.1 | 147.8 | 233.6 |
| | | 2080–2099 | 138.5 | 121.7 | 142.3 | 139.9 | 280.0 | 437.6 | 225.0 | 337.8 | 485.7 | 547.0 | 294.5 | 154.3 | 275.4 |
| **Dua** | KBN | 1986–2005 | 152.5 | 127.2 | 115.7 | 111.3 | 224.3 | 365.9 | 521.5 | 844.3 | 1023.4 | 708.9 | 339.1 | 196.6 | 394.2 |
| | RCP4.5 | 2016–2035 | 222.4 | 182.4 | 164.2 | 140.5 | 435.2 | 503.0 | 743.6 | 1273.0 | 1353.6 | 956.1 | 571.9 | 288.0 | 569.5 |
| | | 2046–2065 | 238.2 | 193.3 | 190.4 | 185.9 | 419.7 | 467.7 | 551.6 | 913.6 | 1358.0 | 1229.7 | 545.3 | 315.5 | 550.7 |
| | | 2080–2099 | 237.9 | 204.5 | 175.4 | 180.7 | 514.8 | 509.3 | 847.2 | 1199.3 | 1568.1 | 1001.3 | 661.1 | 310.2 | 617.5 |
| | RCP8.5 | 2016–2035 | 205.7 | 170.2 | 152.0 | 135.3 | 402.9 | 515.3 | 814.9 | 1360.1 | 1238.8 | 831.5 | 572.6 | 297.4 | 558.0 |
| | | 2046–2065 | 258.2 | 206.8 | 202.7 | 181.3 | 466.2 | 557.5 | 701.3 | 1052.9 | 1408.0 | 1285.1 | 531.7 | 335.3 | 598.9 |
| | | 2080–2099 | 238.2 | 192.8 | 165.3 | 153.4 | 459.8 | 593.2 | 793.0 | 1079.8 | 1250.9 | 1120.0 | 664.9 | 321.8 | 586.1 |
| **Yen Thuong** | KBN | 1986–2005 | 212.5 | 176.0 | 158.6 | 150.6 | 349.0 | 459.9 | 589.5 | 1002.3 | 1371.5 | 1073.4 | 519.2 | 297.9 | 530.0 |
| | RCP4.5 | 2016–2035 | 299.8 | 239.2 | 215.8 | 188.4 | 526.6 | 622.7 | 831.5 | 1490.7 | 1732.5 | 1303.5 | 794.4 | 422.9 | 722.3 |
| | | 2046–2065 | 331.4 | 258.5 | 260.4 | 263.2 | 517.5 | 555.5 | 627.1 | 1114.5 | 1670.5 | 1577.0 | 855.0 | 495.2 | 710.5 |
| | | 2080–2099 | 319.6 | 268.8 | 228.7 | 240.0 | 650.1 | 618.3 | 920.0 | 1454.4 | 1880.1 | 1398.3 | 972.6 | 463.7 | 784.6 |
| | RCP8.5 | 2016–2035 | 269.8 | 216.0 | 198.7 | 187.8 | 564.8 | 641.9 | 938.2 | 1640.1 | 1570.9 | 1188.7 | 804.8 | 435.9 | 721.5 |
| | | 2046–2065 | 356.8 | 268.7 | 264.6 | 245.6 | 638.0 | 680.5 | 849.1 | 1255.8 | 1774.4 | 1779.6 | 797.7 | 510.5 | 785.1 |
| | | 2080–2099 | 320.7 | 261.6 | 232.7 | 220.9 | 559.9 | 722.4 | 891.0 | 1299.7 | 1550.0 | 1557.3 | 956.2 | 478.8 | 754.3 |
| **Hoa Duyet** | KBN | 1986–2005 | 42.6 | 34.7 | 28.5 | 27.3 | 54.9 | 46.7 | 36.1 | 77.4 | 190.8 | 260.7 | 128.8 | 69.8 | 83.2 |
| | RCP4.5 | 2016–2035 | 56.7 | 46.0 | 41.9 | 39.6 | 95.9 | 99.6 | 44.6 | 118.8 | 251.5 | 264.1 | 190.6 | 85.6 | 111.3 |
| | | 2046–2065 | 60.7 | 50.2 | 46.3 | 42.8 | 102.7 | 78.1 | 60.1 | 85.8 | 162.0 | 275.0 | 238.2 | 111.5 | 109.4 |
| | | 2080–2099 | 56.9 | 49.6 | 42.1 | 40.1 | 105.3 | 72.9 | 76.3 | 105.5 | 194.5 | 256.5 | 233.4 | 91.0 | 110.3 |
| | RCP8.5 | 2016–2035 | 51.5 | 41.5 | 38.6 | 38.0 | 97.4 | 83.7 | 62.7 | 117.1 | 219.1 | 237.3 | 210.9 | 92.2 | 107.5 |
| | | 2046–2065 | 60.1 | 50.3 | 47.5 | 45.5 | 109.3 | 67.4 | 74.2 | 81.7 | 214.5 | 294.7 | 201.8 | 106.9 | 112.8 |
| | | 2080–2099 | 55.4 | 46.7 | 40.5 | 42.3 | 114.6 | 82.8 | 66.4 | 89.2 | 225.7 | 280.0 | 207.3 | 88.9 | 111.6 |
| **Son Diem** | KBN | 1986–2005 | 18.1 | 15.6 | 15.1 | 13.4 | 35.2 | 26.1 | 29.2 | 44.9 | 97.5 | 111.4 | 52.1 | 26.6 | 40.4 |
| | RCP4.5 | 2016–2035 | 24.8 | 21.4 | 33.1 | 34.0 | 47.9 | 40.2 | 18.9 | 57.7 | 128.2 | 144.5 | 70.9 | 34.4 | 54.7 |
| | | 2046–2065 | 28.5 | 23.2 | 36.1 | 39.1 | 64.0 | 45.1 | 24.3 | 49.4 | 89.4 | 162.0 | 99.1 | 43.2 | 58.6 |
| | | 2080–2099 | 22.0 | 18.9 | 34.4 | 35.0 | 79.6 | 39.8 | 31.3 | 52.4 | 118.7 | 128.3 | 100.9 | 39.3 | 58.4 |
| | RCP8.5 | 2016–2035 | 21.1 | 16.6 | 29.2 | 38.2 | 45.5 | 42.8 | 29.8 | 56.6 | 99.0 | 119.7 | 79.6 | 36.3 | 51.2 |
| | | 2046–2065 | 28.9 | 21.5 | 41.5 | 26.4 | 59.7 | 40.4 | 26.2 | 46.8 | 113.6 | 150.1 | 77.3 | 40.2 | 56.0 |
| | | 2080–2099 | 21.6 | 17.0 | 31.4 | 23.5 | 79.1 | 34.7 | 38.5 | 53.0 | 118.5 | 166.6 | 80.0 | 34.6 | 58.2 |

### *3.3. Assessment of the climate change impact on the distribution of flood season in the year*

Among the 3 areas in the Ca River basin assessed, the distribution of flood season months in the year in the Hieu river basin (Nghia Khanh station) is most affected by climate change. In the base period, this area has a flood season lasting for 3 months from August to October, however, in future periods according to climate change scenarios, the flood season appears earlier, even earlier than 3 months, and most periods end more than 1 month later (Table 4, Figure 11). Specifically:

– During the period 2016–2035, the flood season appears 3 months earlier in both scenarios RCP4.5 (extended by 3 months, starting from May) and RCP8.5 (extended by 4 months, starting from May to November). Particularly for the RCP8.5 scenario, the flood season ends 1 month later than the baseline period.

– In the period 2046–2065, the flood season ends 1 month later (ending November) compared with the baseline period in both RCP4.5 and RCP8.5 scenarios. Particularly for the RCP4.5 scenario, the flood season appears 2 months earlier than the baseline period.

– In the period 2080–2099 under both RCP4.5 and RCP8.5 scenarios, the start time of the flood season remains unchanged but the flood season ends 1 month later than the baseline period. Thus, the flood season lasts for 1 month more.

In the upstream area of the Ca River basin (Dua station), in the base period, the flood season lasts for 4 months from July to October, however, in most future periods CC scenarios, flood season appears in the same month and ends in the same month or 1 month later, only the period 2080–2099 (RCP8.5) it appears 1 month earlier (Table 3, Figure 10). Specifically:

– In the period 2016–2035, the flood season occurs in the same month and ends 1 month later than the baseline period in both RCP4.5 and RCP8.5 scenarios (extended 1 month more).

– In the period 2046–2065, the flood season appears and ends in the same month as the base period in the RCP8.5 scenario; appears in the same month and ended 1 month later than the baseline period in the RCP4.5 scenario (the flood season was extended 1 month).

– In the period 2080–2099, the flood season occurs in the same month and ends 1 month later than the baseline period in the RCP4.5 scenario (extended 1 month); appears 1 month earlier and ended 1 month later than the baseline period in RCP4.5 scenario (extended 2 months).

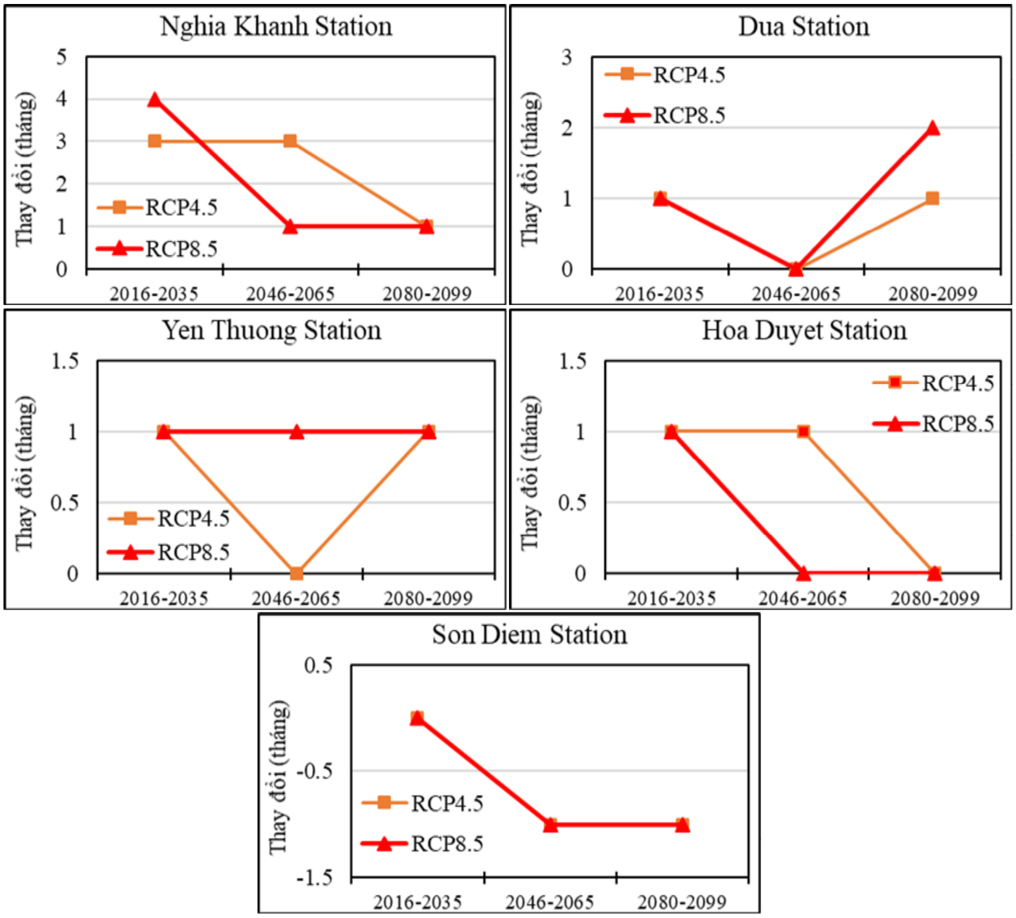

**Figure 11.** Changes in the number of months in the flood season in the basin of some hydrological stations in the Ca River basin in periods under the scenarios RCP4.5 and RCP8.5 compared to the baseline period.

In the southern part of the Ca River basin, on Ngan Sau River basin (Hoa Duyet station) and Ngan Pho River basin (Son Diem station), the flood seasons are also different in the base period. Flood season lasts for 3 months from September to November on the Ngan Sau river basin and 4 months from August to November on the Ngan Pho River basin. On both these river basins, in the future periods under both RCP4.5 and RCP8.5 scenarios, the flood season ends in the same month compared to the baseline period, ending only 1 month later in the period 2046–2065 according to the RCP4.5 scenario on the Ngan Sau river basin (Table 3, Figure 10). On the Ngan Sau river basin, the flood season in periods of CC scenarios is largely unchanged compared to the baseline period, lasting only more than 1 month in the period 2016–2035 under two scenarios RCP4.5 and RCP8. 5 (appearing 1 month earlier) and the period 2046–2065 under the RCP4.5 scenario (ending 1 month later). On the Ngan Pho river basin, according to both RCP4.5 and RCP8.5 scenarios, the flood season changes compared to the baseline period in the period 2016–2035 and occurs 1 month later in the two periods 2046–2065 and 2080–2099 (1 month less).

Up to Yen Thuong station, in the base period, the flood season lasts for 4 months from July to October, in most future periods under CC scenarios, the flood season occurs in the same month and ends 1 month later compared to the baseline period (extending 1 month more), in the period 2046–2065 (RCP4.5) it appears and ends 1 month later than the baseline period (the number of months in the flood season does not change) (Table 4, Figure 11).

## 4. Conclusion

Climate change affects the distribution of flows in flood season in all areas in the Ca River basin. Of which, the variation of the flood season is strongest on the Hieu river basin in the north of the Ca River basin and the impact decreases gradually from the north to the south. The cause of changes of flows in the flood–season distribution is attributed to changes in the rainfall patterns derived from the CC scenarios.

Climate change can shift the flood season earlier and end later in some periods under the RCP4.5 and RCP8.5 scenarios compared to the baseline. The flood season occurs up to 3 months earlier in the period 2016–2035 according to both RCP4.5 and RCP8.5 scenarios on the Hieu river basin, the rest appear and end 1 month earlier or later compared to the baseline period. However, this study is solely based on one hydrological model and one climate scenario that may cause uncertainties. Further studies using ensemble of hydrological models and climate models to validate this finding in other basins having similar conditions are necessary.

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