IRRIGATION WATER REQUIREMENTS IN THE TROPICAL BASIN USING CROPWAT 8.0 MODEL: A CASE STUDY OF THE BA RIVER BASIN, VIETNAM

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Abstract: In the context of climate change and the current scarcity of water resources, assessing and forecasting irrigation water requirements are crucial for water resource management in tropical river basins. This research applied the CROPWAT 8.0 model together with ArcGIS software and CMhyd model to determine the current irrigation water requirement for crops in four sub-basins in the Ba River basin and projected it until 2100 under the scenarios of the CMIP6 model. Under the impact of climate change, the irrigation water requirement tends to increase, especially during the dry months in sub-basin 4 in the lower Ba River basin. Rice is the crop with the highest water requirement among all four sub-basins. This presents a significant challenge for the local managers. The results of this research can serve as a basis for planning irrigation strategies that align with the characteristics of crops, natural conditions, socio-economic factors, and adaptation to climate change. Additionally, this research can be used as a reference to support decision-makers in the rational management and use of water resources in tropical basins, select appropriate irrigation methods for each type of crop, and consider economic calculations in national planning to determine an effective crop structure for each river basin.

Keywords: Ba River basin, CMIP6, CROPWAT 8.0, tropical basin, irrigation water requirement

1. INTRODUCTION

The impact of climate change on the available water resources and irrigation water requirements is crucial for assessing agricultural productivity and economic development in various regions (Rastegaripour et al., 2024; Shayanmehr et al., 2022). Water is the most important input for agriculture, and efficient use and supply of water is urgently needed. Severe water shortages have occurred in many countries, including Vietnam. Water for agriculture is becoming increasingly scarce owing to the growing demand for water from different sectors. Agriculture is the largest water consumer (> 80 %) in Vietnam and other tropical countries (Tukimat et al., 2017), therefore, more efficient use of water in agriculture must be considered. Subtropical and tropical river basins often have uneven distributions of water resources throughout the year (de Sousa et al., 2021; Kang et al., 2023). A better understanding of the complex interactions between climate, water, and agriculture development is a priority task for tropical river basins. Although the average annual rainfall in tropical river basins, including the Ba River basin, is not low, the temporal distribution of rainfall is uneven, leading to water shortages during the dry season, which affects crop yield and production.

The Coupled Model Intercomparison Project (CMIP), particularly its most recent phase, CMIP6, plays a critical role in understanding future climate changes using General Circulation Models (GCMs) (Meinshausen et al., 2020). These models offer insight into how global and regional climates might evolve under various socioeconomic and emission scenarios, helping researchers and policymakers prepare for future climate impacts. These studies (Gusain et al., 2020; Li et al., 2021), underscore the significant improvements in climate modeling introduced by CMIP6, particularly in simulating regional climate phenomena, such as monsoons,

extreme precipitation, and their impacts on water resources and agriculture. The use of Shared Socio-economic Pathways (SSPs) and long-term projections further enhances our understanding of potential climate outcomes under different socio-economic scenarios, providing critical data for future planning and mitigation strategies. The insights gained from these models are crucial for addressing the challenges posed by climate change, particularly water scarcity.

The CROPWAT 8.0 model (FAO, 2009) is a widely used tool for calculating the irrigation water requirements and irrigation scheduling. Song et al. (2015) assessed the water requirements of rice crops by using the CROPWAT model. Similarly, Banerjee et al. (2016) used CROPWAT 8.0 to predict irrigation water requirements for potatoes in the lower Ganges delta of India. Meanwhile, Thazin (2019) applied this model to calculate the water requirements for various crops in the Taungdwingyi township. The research by Balan & Joseph (2021) applied this model to predict the water requirement and schedule irrigation for banana plants in the Manali area of Thrissur, Kerala. Daoed et al. (2018) evaluated the ability of the CROPWAT 8.0 model to determine drought vulnerability in the watersheds of West Sumatra, Indonesia. This study showed that the CROPWAT 8.0 model can predict water requirements under drought conditions and support efficient water management. Similarly, Ehsani et al. (2012) used CROPWAT 8.0 to estimate evapotranspiration and crop water requirements in the Steppic region of Markazi province, Iran. A synthesis of these studies indicates that the CROPWAT 8.0 model is a useful tool for calculating the irrigation water requirements for various crops under different climatic conditions. Several studies have focused on the irrigation demand in the context of irrigation water demand under future climate scenarios. Using crop models such as CROPWAT, combined with regional climate projections from CMIP6, studies such as El-Rawy et al. (2023), Karan et al. (2022), Patidar et al. (2020), and Sharma & Tare (2022) consistently showed that rising temperatures and changing rainfall patterns will increase irrigation demand, placing stress on existing water resources. The results from the model provide important information for water resource management and effective irrigation planning, and have the potential for widespread application in different climatic and environmental conditions.

In recent years, drought and water scarcity in the Ba River basin have become increasingly severe. During the early months of 2024, rainfall across the Ba River basin was significantly below the long-term average. Since late 2023, water levels in rivers and streams have been gradually declining, resulting in localized water shortages in areas lacking access to irrigation sources or situated far from irrigation infrastructure. However, calculating and forecasting irrigation water demand for tropical river basins remains challenging due to a lack of input data and the absence of appropriate approaches.

This research was conducted with the aim of calculating the current irrigation water requirement and forecasting irrigation requirement under the SSP scenarios for the main crops in the sub-basins of the Ba River basin using the CROPWAT 8.0 model. The calculation results are a scientific basis to assist planners in developing appropriate water usage plans for a typical tropical river basin.

2. MATERIALS AND METHODS

2.1. Study area and materials

The Ba River basin (Figure 1) covers an area of 13848 km^2, with a main river length of 388 km. It originates from the Ngoc Ro Mountain at an elevation of 1200 m and flows into the sea at the Da Rang estuary. The Ba River basin is the only basin that spans both sides of the high Truong Son Mountain range, and it can be considered a transitional basin from the central highlands to the south-central coast of Vietnam. The Ba River basin has a unique geographical position and is characterized by rich and diverse natural resources. It holds significant importance in terms of the economy, politics, security, and defense of Vietnam in general, and specifically for the Central Highlands and South-Central Coast.

The Ba River basin spans three provinces, Gia Lai, Dak Lak, and Phu Yen, covering 22 districts. There are four meteorological stations in the basin: Khe, AyunPa, MDrak, and Tuy Hoa (Figure 1). Based on the distribution of water resources, administrative boundaries, and network of meteorological stations, we divided the Ba River basin into four sub-basins (Table 1 and Figure 1).

The average annual temperature in the upstream region of the basin ranges from 23.5 to 24.6 °C, in the midstream region from 23.6 to 24.7 °C, and in the downstream region from 26.5 to 27.6 °C. Rainfall in the basin is lower than the national average for Vietnam and is unevenly distributed. The average annual rainfall across the entire basin is approximately 1650 mm. The average annual rainfall at An Khe, AyunPa, MDrak, and Tuy Hoa stations are 1590 mm, 1249 mm, 2123 mm, and 2052 mm, respectively. Rainfall is concentrated mainly during the rainy season, accounting for 84 % of the annual rainfall from June to December in sub-basin 1, 90 %

Table 1. List of districts and sub-basins in the Ba River basin.

District	Area (km^2)	Sub-basin	Province
An Khe	175.5	1	
KBang	1266.1	1	
Dak Doa	312.6	1	
Mang Yang	1122.6	1	
Krong Chro	1278.7	1	
Chu Se	499.6	1	Gia Lai
Dak Po	502.4	1	
AyunPa	288.5	2	
Ia Pa	870.7	2	
Krong Pa	1583.3	2	
Phu Thien	503.7	2	
Chu Puh	180.6	2	
Ea HLeo	390.8	2	
Krong Nang	525.2	3	Dak Lak
Ea Kar	562.4	3	
MDrak	902.9	3	
Tuy Hoa	105.5	4	
Son Hoa	751.0	4	
Song Hinh	895.4	4	
Tay Hoa	628.8	4	Phu Yen
Phu Hoa	258.7	4	
Dong Hoa	243.2	4	

from May to November in sub-basin 2, 76 % from May to December in sub-basin 3, and 79 % from September to December in the coastal plain area of sub-basin 4. Heavy rain occurred, especially in September and October. During the dry season, rainfall accounts for only 10 - 25 % of the annual total. The months with the lowest rainfall were typically January, February, and March. The difference in rainfall between the wettest and driest months is significant. The rainfall patterns differ between the plains and mountainous areas; the rainy season in the plains is usually short, with concentrated rainfall, whereas in mountainous areas, rainfall is more evenly distributed across the months. In contrast to rainfall, the average annual as well as the average dry-season evapotranspiration within the basin does not vary significantly between sub-basins. The average annual evapotranspiration in sub-basins 1, 2, 3 and 4 are 1297, 1394, 1209 and 1417 mm, respectively. The average dry-season evapo-transpiration in sub-basins 1 and 4 are in sub-basins 1, 2, 3 and 4 are 442, 687, 412 and 1065 mm, respectively. Therefore, uneven rainfall distribution in tropical river basins poses challenges for agricultural development.

Crop development in the Ba River basin also varied significantly between sub-basins. Statistics on crop areas in the Ba River basin for 2020 are presented in Table 2. Rice, corn, cassava, sugarcane, and coffee are the main crops in sub-basin 1. Corn and coffee are the main crops in sub-basin 2. Rice, corn, and cassava are the main crops in sub-basin 3, and rice, cassava, and sugarcane are the main crops in sub-basin 4. The different crop distributions make it essential to calculate the water requirements of each sub-basin.
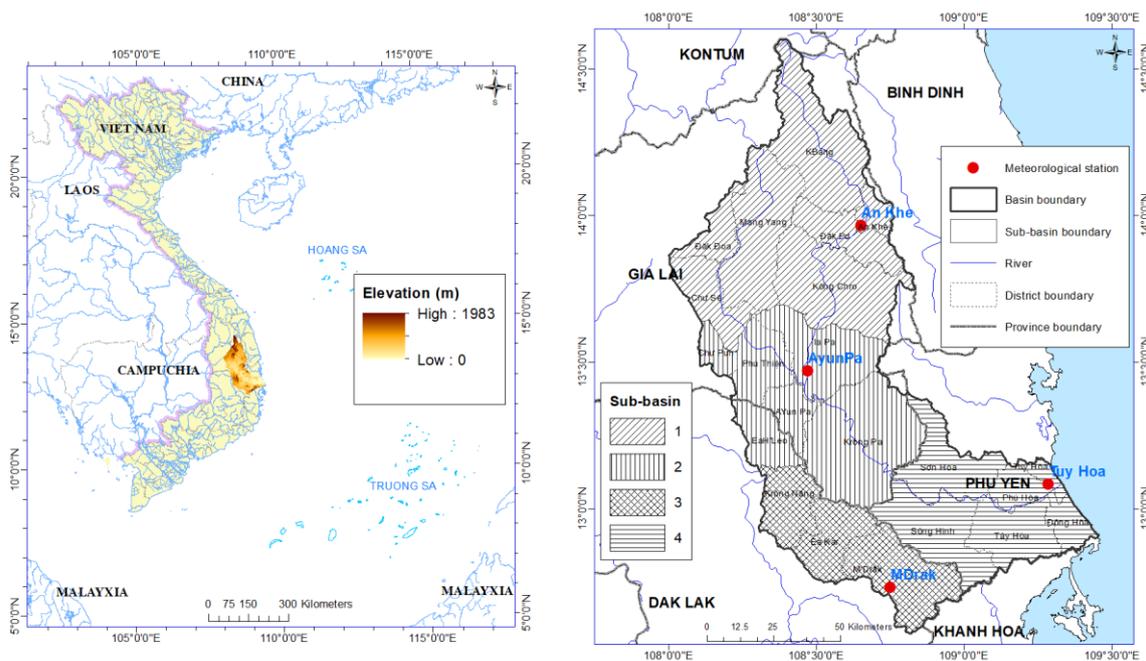

Figure 1. Network of meteorological stations and four sub-basins in the Ba River basin.

Table 2. Crop areas in the Ba River basin in 2020 (ha).

Cultivated crop	Sub-basin 1	Sub-basin 2	Sub-basin 3	Sub-basin 4
Winter - Spring rice	6094	11878	5671	20516
Summer - Autumn rice	16186	17482	6345	19806
Maize	15028	11496	16400	2945
Sweet potato	1413	1575	1541	
Cassava	20651	37510	8849	22541
Sugarcane	16284	6530	8990	15631
Peanuts		580	310	
Soybeans		72	161	
Cashew	259	6849	2351	
Pepper	7138	1536	4454	
Rubber	10818	3744	4181	4106
Coffee	3	9227	26063	
Citrus	3367	549	1298	974

(D.L.P.S. Office, 2023; G.L.P.S. Office, 2023; P.Y.P.S. Office, 2023)

The research utilizes the following data sources for calculations:

• Meteorological data from 1981 to 2020 at four meteorological stations in the basin were used to calculate the reference evapotranspiration (ETo). These data included latitude, longitude, station elevation, maximum and minimum temperatures, relative humidity, wind speed, and sunshine hours. This information was compiled into the input dataset for the CROPWAT 8.0 model;

• Data on the types of crops in the basin were collected from the Statistical Yearbooks of the three provinces in the Ba River basin;

• The land cover map of the Ba River basin for the period 2017-2023 was extracted from the ArcGIS Living Atlas of the World, which is based on Sentinel-2 imagery with a 10-meter resolution;

• Soil data were collected from FAO datasets and supplemented with the results from field surveys conducted in July 2024 in the Ba River basin;

• Data from the EC-Earth3-Veg model (CMIP6) were extracted by ArcGIS Software and bias-corrected to build climate change scenarios SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 (for the periods 2021 - 2040, 2041 - 2060, 2061 - 2080, and 2081 - 2100) for the four sub-basins in the Ba River basin.

2.2. Methods

To address the challenges of calculating and forecasting water demand for agricultural development in tropical river basins, this research adopts an integrated approach that combines models and software tools, as described below.

CROPWAT is a decision support tool that was developed by the Land and Water Development Division of the Food and Agriculture Organization (FAO). CROPWAT 8.0 for Windows, is a computer program used to calculate crop water and irrigation requirements based on the soil, climate, and crop data. In addition, the program allows for the development of irrigation schedules under different management conditions and the calculation of water-supply plans for various crop patterns. CROPWAT 8.0 can also be used to evaluate irrigation practices. The development of irrigation schedules in CROPWAT 8.0 is based on daily soil-water balance using various user-defined options for irrigation and water supply management conditions. The water supply scheme is calculated according to the cropping pattern defined by the user, which can include up to 20 crop types (FAO, 2009). There are 12 types of crops in the Ba River basin (Table 2). To calculate irrigation water requirements, CROPWAT requires ETo data. CROPWAT allows users to input either measured ETo values or temperature, humidity, wind speed, and sunshine hour data to calculate ETo using the Penman - Monteith formula (FAO, 2009). In this study, the CROPWAT model was applied to calculate irrigation levels for crops such as rice, maize, potatoes, cassava, sugarcane, peanuts, soybeans, cashews, pepper, rubber, coffee, and fruit trees in a tropical river basin with an uneven rainfall distribution. Meteorological data from the four stations were used to calculate ETo. The Penman-Monteith method (Allen et al., 1998) was used to determine ETo. The average annual ETo as well as the average dry-season ETo within the basin does not vary significantly between sub-basins. The average annual ETo values in sub-basins 1, 2, 3 and 4 are 3.75, 3.81, 3.48 and 3.88 mm/day, respectively. The average dry-season ETo in sub-basins 1 and 4 are in sub-basins 1, 2, 3 and 4 are 3.84, 3.69, 3.48 and 4.23 mm/day, respectively. In certain basins such as Oran and Algiers (Algeria), the average annual ETo is 3.38 mm/day and 3.71 mm/day, respectively, comparable to the ETo in the sub-basins of the Ba River basin. However, the rainfall in these areas is significantly lower, at only 336.6 mm and 555.6 mm per year (Abdelkader, 2023).

The crop coefficient (Kc) values were obtained from the CROPWAT. The Kc values for the initial, middle, and late growth stages of the annual and seasonal crops were used for rice, corn, potato, cassava, sugarcane, peanuts and, soybeans. For the perennial crops (cashew, pepper, rubber, coffee and, fruit trees), the same Kc values were used throughout the year.
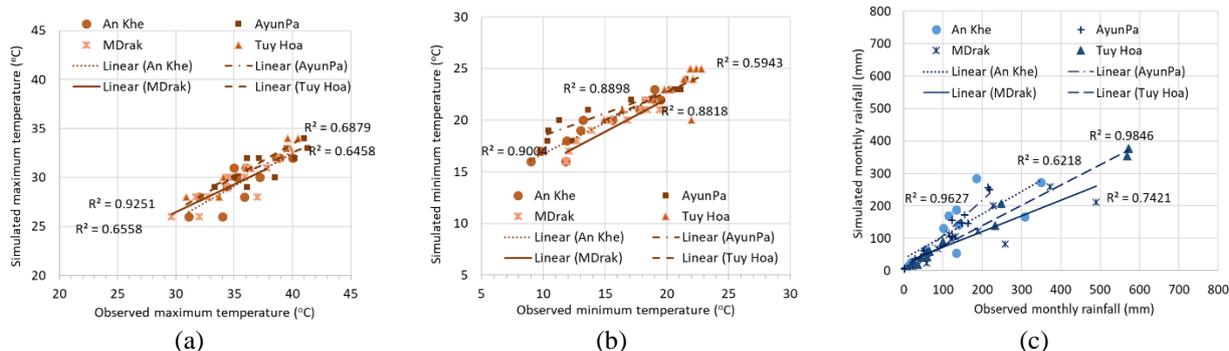
Figure 2. The relationship between maximum temperature data (a), minimum temperature data (b), and monthly precipitation (c) at observation stations and simulated data by WorldClim2.

ArcGIS 10.5 software was used to extract and calculate land cover data (2017 - 2023) downloaded from the ArcGIS Living Atlas for the four sub-basins in the Ba River basin.

The research also built a climate change scenario for the Ba River basin up to 2100 with data extracted from the Climate Model Intercomparison Project Phase 6 (CMIP6) by ArcGIS software and bias corrected by the CMhyd model. The climate change scenario for the Ba River basin was constructed using the global climate model EC-Earth3-Veg (CMIP6) under the WorldClim2 program. Simulated climate data from 1981 to 2020 at four meteorological stations were used. With resolutions of 30 s and 2.5, 5, and 10 min, WorldClim2 generated simulated and predicted climate datasets. WorldClim2 provides monthly simulated datasets for 1960 - 2021, including temperature, precipitation, solar radiation, pressure, and wind speed. Using ArcGIS 10.5 software, the research extracted maximum temperature, minimum temperature, and precipitation data at four observation stations, calculated monthly average maximum temperature, minimum temperature, and precipitation for the period 1981 - 2020, and compared these with observed data for the same period. The reliability of the forecast results was tested by research using a 2.5-minute resolution version. The correlation coefficient results for the four stations are shown in Figure 2.

The maximum temperature at Tuy Hoa station, the minimum temperature at An Khe, AyunPa, and MDrak stations, and the precipitation at AyunPa and Tuy Hoa stations have a correlation coefficient between the observed data and simulated data greater than 0.8. The remaining factors had correlation coefficients less than 0.8. Therefore, to correct for these deviations, we used CMhyd (climate model data for hydrological modeling). Using observed data from meteorological stations, simulated data from WorldClim2, and forecast data according to the scenarios of the EC-Earth3-Veg model (CMIP6), we

applied the CMhyd model to develop climate change scenarios for the sub-basins of the Ba River basin.

3. RESULTS AND DISCUSSIONS

3.1. Variations of land cover in the Ba River basin

Based on the land cover map for the 2017 - 2023 period, collected from ArcGIS Living Atlas of the World, which was built from Sentinel-2 imagery with a 10 m resolution, we used ArcGIS software to extract data for the Ba River basin. Land cover changes from 2017 to 2023 are shown in Figure 3. According to the statistical yearbook, the total area of agricultural land in the Ba River basin is 6491.7 km^2, accounting for approximately 47 % of the total basin area. However, according to the land cover map, the annual cultivated land area in the basin (Table 3) accounts for only 31 – 34 % of the total basin area, equivalent to 67 – 72 % of the potential agricultural land area. The variations in cultivated area among the sub-basins were approximately 10 % between years. The primary reason for the underutilization of agricultural land is the insufficient supply of irrigation water, particularly during the dry months in tropical river basins. Therefore, calculating and forecasting irrigation water demand for crops in tropical river basins to ensure the rational use of water resources is essential.

Table 3. Crop area in sub-basins from 2017 - 2023 (km^2).

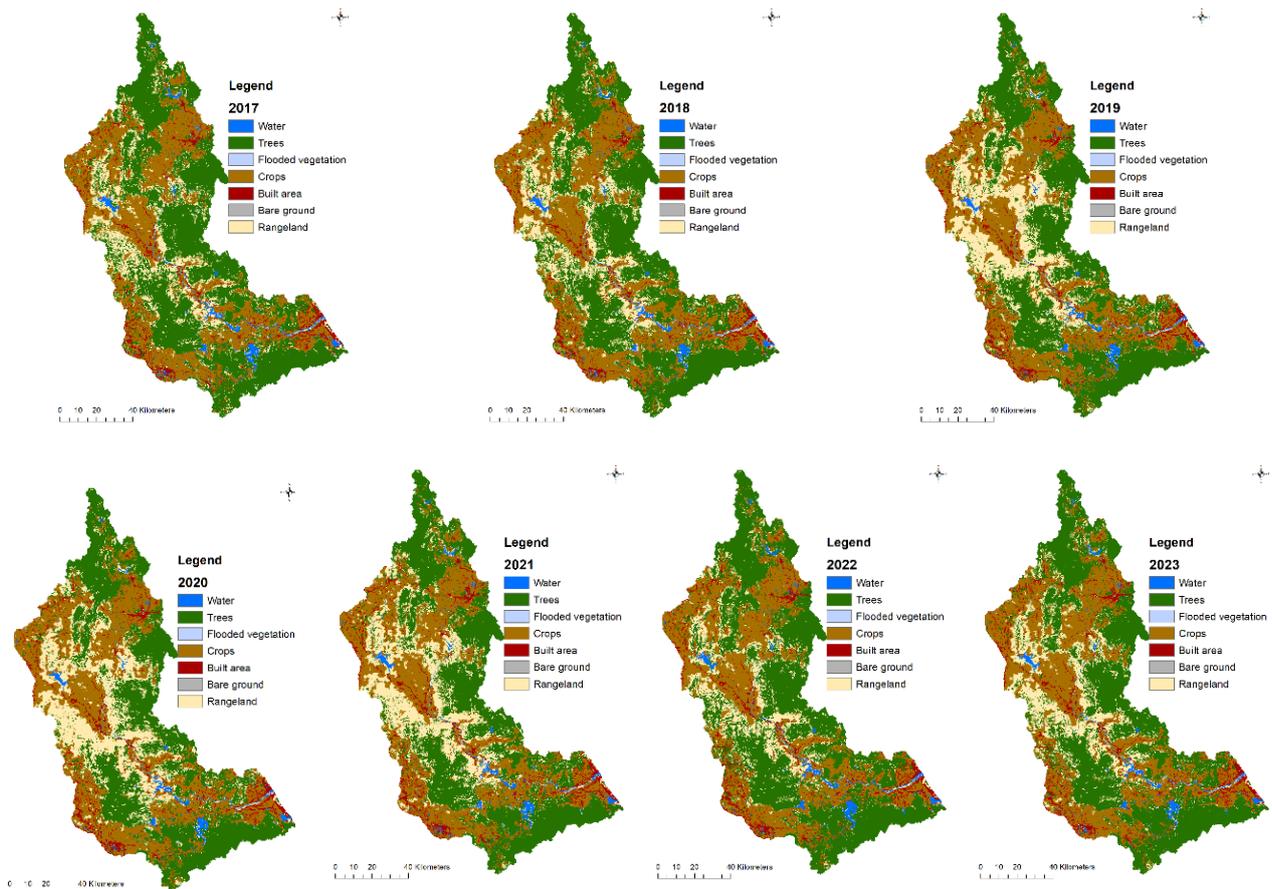| Year	Sub-basin 1	Sub-basin 2	Sub-basin 3	Sub-basin 4	Sum
2017	1740.9	911.8	789.9	919.6	4362.2
2018	1829.1	1005.6	829.5	989.2	4653.4
2019	1745.2	978.5	845.6	995.8	4565.1
2020	1841.7	957.9	858.0	993.8	4651.4
2021	1800.4	940.0	801.7	955.9	4498.0
2022	1876.1	982.8	755.2	907.6	4521.8
2023	1878.3	1057.8	792.1	930.7	4658.9

Figure 3. Landcover map of the Ba River basin (2017 - 2023).

3.2. The present irrigation water requirement in the Ba River basin

Based on the measurement data and CROPWAT data, an input dataset was built for four sub-basins in the Ba River basin. Owing to the differing climatic conditions and crop structures in the four sub-basins, irrigation water requirements vary significantly. Currently, rice, maize, cassava, and sugarcane are the main crops in the Ba River basin. The proportion of these crops varies by sub-basin. The results of the irrigation calculations for the sub-basins are shown in Figure 4. Sub-basin 4 had the highest irrigation level, whereas sub-basin 3 had the lowest irrigation level because it was influenced directly by rainfall and its distribution throughout the year. In September and October, owing to the large amount of rainfall across all four sub-basins, the irrigation water requirement was lower, particularly in October, which was 0. November, the last month of the rainy season, showed relatively uniform irrigation levels across the sub-basins. Variability in actual irrigation levels reflects the instability of water resources in tropical river basins. Except for October with an irrigation coefficient of 0, irrigation levels

range from 0.02 to 0.35 l/s/ha in sub-basin 1; from 0.02 to 0.37 l/s/ha in sub-basin 2; from 0.01 to 0.35 l/s/ha in sub-basin 3; and from 0.03 to 0.39 l/s/ha in sub-basin 4.

Detailed calculations of the water requirements for various crops in the sub-basins are shown in Figure 5. Generally, the highest water requirement in all four sub-basins was irrigation water for rice during both the winter-spring and summer-autumn seasons. Perennial crops, such as pepper and rubber, have the highest water requirements during the dry months.

Sub-basin 1: This sub-basin has medium irrigation water demand compared to other sub-basins
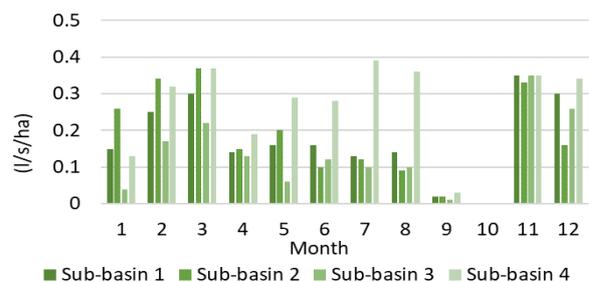

Figure 4. Calculated results of irrigation water requirement for sub-basins.

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in the basin due to relatively evenly distributed rainfall despite the low total annual rainfall.

Sub-basin 2: Sub-basin 2 has the lowest rainfall, represented by the AyunPa station. Although the rainfall distribution is more even than that in the downstream area, low rainfall in the dry season causes many difficulties in water use in the sub-basin. The highest irrigation water requirement in the whole basin was determined to be 1.19 l/s/ha in March during the preparation period for summer-autumn rice in sub-basin 2.

Sub-basin 3: Owing to the large and evenly distributed water supply in this sub-basin, it has the smallest irrigation level.

Sub-basin 4: This sub-basin, located in the lower Ba River basin, has high rainfall but uneven distribution throughout the year and a short rainy season lasting only four months from September to December. Consequently, sub-basin 4 had the highest irrigation water requirement. The irrigation water requirement for summer-autumn rice is also quite high, with a requirement of 0.84 l/s/ha.

Calculations show that the irrigation demand for staple crops (rice, maize, and cassava), particularly rice, accounts for a higher proportion compared to other crops in the basin. In sub-basin 4, a downstream area with significant economic activities, rice irrigation remains predominant. The Ba River basin, characterized by a tropical climate and uneven water distribution concentrated mainly during the flood season, requires accurate forecasts of water demand. This is crucial for ensuring efficient water allocation and supporting the development of effective national economic planning, thereby optimizing crop structure.

3.3. Calculation of CMIP6 climate change scenarios for the Ba River basin

This research used observed maximum temperature, minimum temperature, and rainfall data for the period 1981 - 2020, along with simulated data extracted from WorldClim2 at four meteorological stations: An Khe, AyunPa, M'Drak, and Tuy Hoa. These datasets served as the basis for calibrating predicted data derived from climate change scenarios.
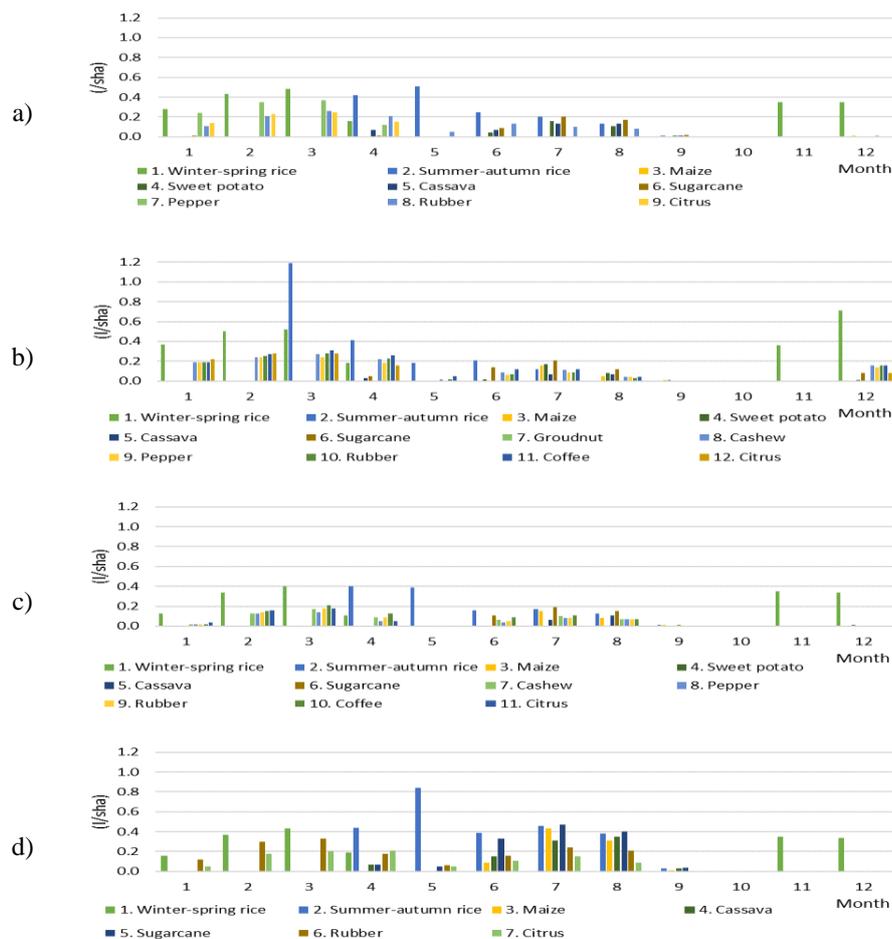
Figure 5. Calculated results of irrigation water requirement in sub-basin 1 (a), sub-basin 2 (b), sub-basin 3 (c), sub-basin 4 (d).

Figure 6. Predicted maximum temperature and minimum temperature for the periods 2021 - 2040, 2041 - 2060, 2061 - 2080, and 2081 - 2100 under SSP scenarios at An Khe, AyunPa, MDrak and Tuy Hoa stations.

Figure 7. Predicted average rainfall for the periods 2021 - 2040, 2041 - 2060, 2061 - 2080, and 2081 - 2100 under SSP scenarios at An Khe, AyunPa, MDrak and Tuy Hoa stations.

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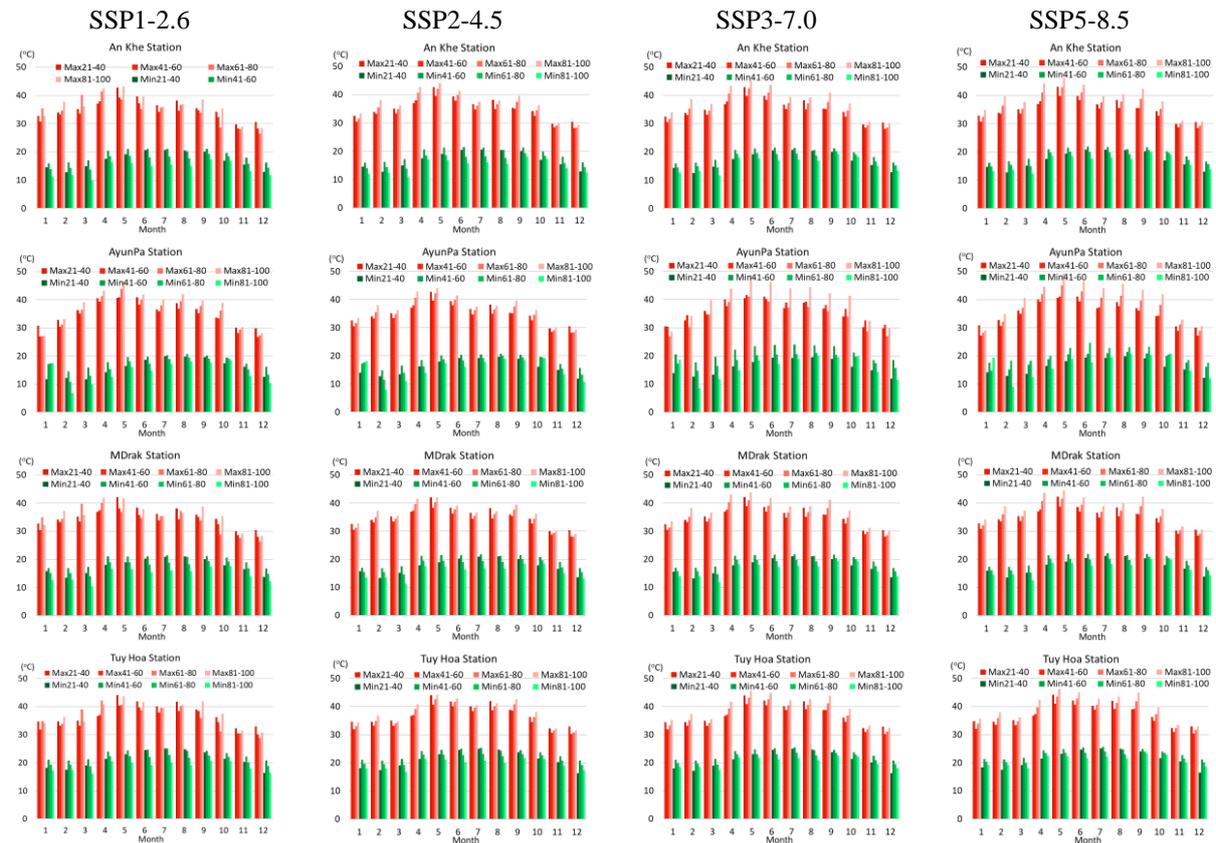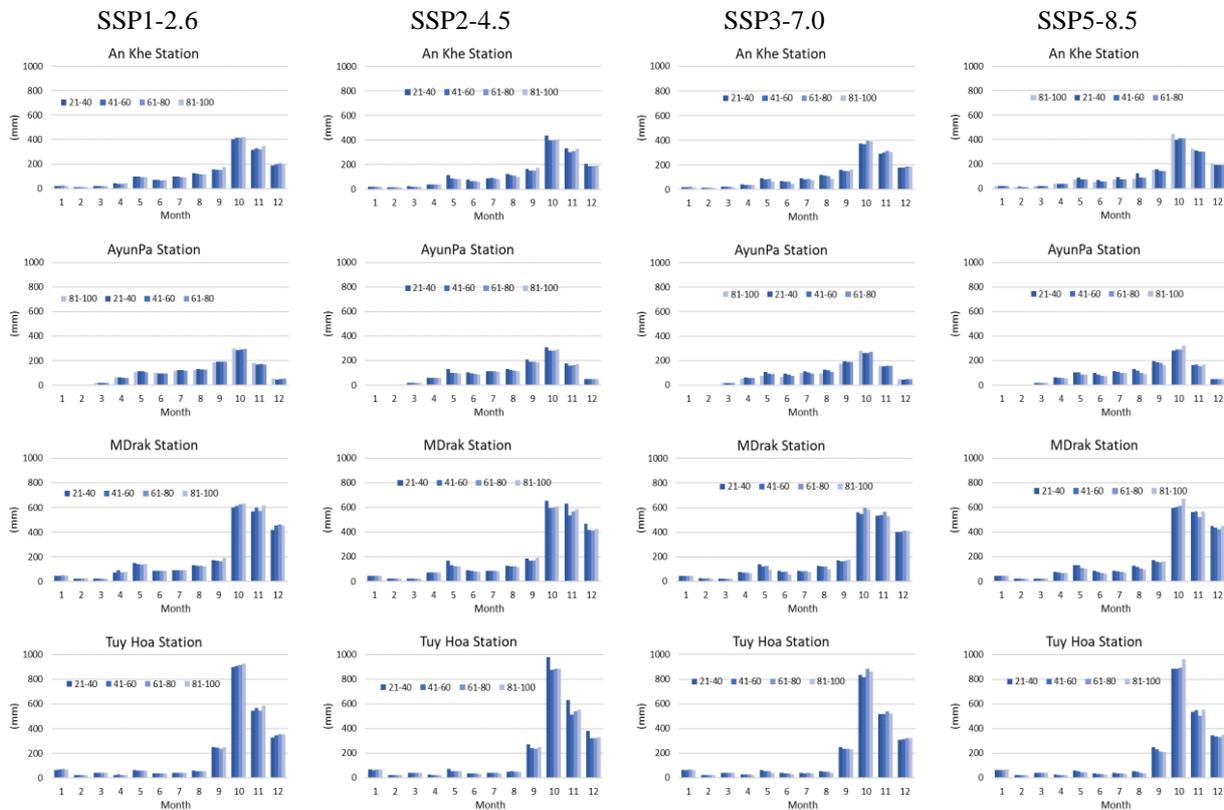Table 4. Irrigation water requirement for 4 sub-basins (l/s/ha).

	Period	1	2	3	4	5	6	7	8	9	10	11	12
						Sub-basin 1							
SSP1-2.6	2021-2040	0.17	0.25	0.29	0.16	0.24	0.29	0.24	0.2	0.09	0	0.35	0.29
	2041-2060	0.17	0.25	0.29	0.17	0.23	0.28	0.22	0.18	0.08	0	0.35	0.29
	2061-2080	0.17	0.25	0.31	0.18	0.24	0.26	0.23	0.2	0.08	0	0.35	0.29
	2081-2100	0.16	0.26	0.29	0.17	0.25	0.28	0.23	0.2	0.07	0	0.35	0.29
SSP2-4.5	2021-2040	0.17	0.24	0.29	0.17	0.23	0.27	0.27	0.21	0.08	0	0.35	0.29
	2041-2060	0.17	0.25	0.29	0.17	0.25	0.28	0.24	0.19	0.08	0	0.35	0.29
	2061-2080	0.17	0.25	0.29	0.17	0.27	0.29	0.25	0.2	0.09	0	0.35	0.29
	2081-2100	0.17	0.26	0.29	0.18	0.29	0.32	0.28	0.23	0.07	0	0.35	0.29
SSP3-7.0	2021-2040	0.17	0.25	0.29	0.16	0.26	0.3	0.26	0.22	0.08	0	0.35	0.29
	2041-2060	0.17	0.25	0.29	0.17	0.27	0.3	0.27	0.2	0.08	0	0.35	0.29
	2061-2080	0.17	0.25	0.29	0.18	0.27	0.31	0.27	0.22	0.1	0	0.35	0.29
	2081-2100	0.16	0.24	0.29	0.19	0.33	0.35	0.28	0.25	0.07	0	0.35	0.29
SSP5-8.5	2021-2040	0.17	0.25	0.29	0.16	0.27	0.29	0.26	0.21	0.09	0	0.35	0.29
	2041-2060	0.17	0.25	0.29	0.18	0.29	0.32	0.28	0.25	0.1	0	0.35	0.29
	2061-2080	0.17	0.26	0.3	0.18	0.31	0.34	0.3	0.27	0.12	0	0.35	0.29
	2081-2100	0.17	0.27	0.31	0.19	0.34	0.38	0.32	0.31	0.13	0	0.35	0.29
						Sub-basin 2							
SSP1-2.6	2021-2040	0.28	0.3	0.33	0.13	0.24	0.17	0.14	0.16	0.02	0	0.35	0.16
	2041-2060	0.28	0.29	0.34	0.13	0.26	0.16	0.12	0.15	0.01	0	0.35	0.15
	2061-2080	0.28	0.29	0.34	0.13	0.34	0.17	0.14	0.17	0.02	0	0.35	0.15
	2081-2100	0.28	0.3	0.34	0.14	0.35	0.18	0.15	0.19	0.02	0	0.35	0.15
SSP2-4.5	2021-2040	0.28	0.31	0.33	0.14	0.21	0.16	0.16	0.16	0.02	0	0.35	0.16
	2041-2060	0.28	0.29	0.34	0.13	0.34	0.17	0.14	0.16	0.01	0	0.35	0.16
	2061-2080	0.28	0.3	0.34	0.14	0.22	0.2	0.17	0.19	0.02	0	0.35	0.16
	2081-2100	0.28	0.3	0.35	0.14	0.24	0.22	0.19	0.22	0.03	0	0.35	0.16
SSP3-7.0	2021-2040	0.28	0.3	0.34	0.13	0.26	0.18	0.16	0.17	0.02	0	0.35	0.17
	2041-2060	0.3	0.33	0.36	0.14	0.23	0.22	0.19	0.2	0.03	0	0.35	0.17
	2061-2080	0.28	0.29	0.34	0.14	0.23	0.22	0.19	0.2	0.02	0	0.35	0.16
	2081-2100	0.29	0.3	0.36	0.15	0.3	0.3	0.24	0.29	0.06	0	0.35	0.16
SSP5-8.5	2021-2040	0.28	0.31	0.34	0.13	0.27	0.17	0.16	0.17	0.02	0	0.35	0.16
	2041-2060	0.28	0.3	0.34	0.13	0.34	0.17	0.15	0.15	0.01	0	0.35	0.16
	2061-2080	0.27	0.31	0.36	0.15	0.27	0.26	0.22	0.26	0.04	0	0.35	0.17
	2081-2100	0.29	0.3	0.37	0.15	0.28	0.29	0.24	0.31	0.08	0	0.35	0.15
						Sub-basin 3							
SSP1-2.6	2021-2040	0.13	0.21	0.31	0.14	0.09	0.24	0.21	0.15	0.04	0	0.35	0.26
	2041-2060	0.12	0.21	0.29	0.13	0.09	0.22	0.18	0.12	0.02	0	0.35	0.26
	2061-2080	0.12	0.21	0.32	0.14	0.1	0.2	0.19	0.14	0.03	0	0.35	0.26
	2081-2100	0.11	0.22	0.29	0.15	0.1	0.22	0.19	0.14	0.02	0	0.35	0.26
SSP2-4.5	2021-2040	0.12	0.21	0.3	0.13	0.08	0.23	0.22	0.16	0.02	0	0.35	0.26
	2041-2060	0.12	0.21	0.3	0.13	0.11	0.23	0.2	0.13	0.03	0	0.35	0.26
	2061-2080	0.13	0.22	0.31	0.14	0.12	0.24	0.21	0.14	0.04	0	0.35	0.26
	2081-2100	0.12	0.22	0.3	0.14	0.13	0.26	0.22	0.16	0.02	0	0.35	0.26

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Table 4. Continued.

	Period												
SSP3-7.0	2021-2040	0.13	0.21	0.31	0.13	0.1	0.25	0.23	0.16	0.03	0	0.35	0.26
	2041-2060	0.12	0.21	0.3	0.13	0.12	0.26	0.23	0.15	0.03	0	0.35	0.26
	2061-2080	0.12	0.21	0.3	0.14	0.13	0.26	0.22	0.16	0.04	0	0.35	0.26
	2081-2100	0.14	0.23	0.3	0.15	0.2	0.36	0.29	0.25	0.06	0	0.35	0.26
SSP5-8.5	2021-2040	0.13	0.21	0.31	0.14	0.11	0.24	0.23	0.16	0.04	0	0.35	0.26
	2041-2060	0.12	0.21	0.3	0.13	0.11	0.25	0.22	0.16	0.04	0	0.35	0.26
	2061-2080	0.13	0.22	0.31	0.14	0.16	0.29	0.24	0.2	0.06	0	0.35	0.26
	2081-2100	0.13	0.23	0.31	0.16	0.16	0.33	0.26	0.24	0.07	0	0.35	0.26
	Sub-basin 4												
SSP1-2.6	2021-2040	0.16	0.31	0.4	0.22	0.43	0.43	0.47	0.44	0.07	0	0.35	0.34
	2041-2060	0.13	0.3	0.39	0.22	0.42	0.41	0.43	0.4	0.06	0	0.35	0.34
	2061-2080	0.14	0.3	0.42	0.24	0.44	0.4	0.44	0.42	0.06	0	0.35	0.34
	2081-2100	0.13	0.32	0.39	0.23	0.44	0.41	0.44	0.42	0.07	0	0.35	0.34
SSP2-4.5	2021-2040	0.15	0.3	0.4	0.22	0.41	0.43	0.48	0.46	0.07	0	0.35	0.34
	2041-2060	0.14	0.3	0.39	0.23	0.45	0.41	0.45	0.41	0.06	0	0.35	0.34
	2061-2080	0.14	0.31	0.4	0.23	0.46	0.43	0.46	0.43	0.07	0	0.35	0.34
	2081-2100	0.14	0.32	0.4	0.23	0.46	0.44	0.47	0.44	0.07	0	0.35	0.34
SSP3-7.0	2021-2040	0.16	0.31	0.41	0.22	0.44	0.43	0.48	0.45	0.07	0	0.35	0.34
	2041-2060	0.15	0.3	0.39	0.23	0.46	0.43	0.46	0.42	0.06	0	0.35	0.34
	2061-2080	0.14	0.31	0.4	0.23	0.46	0.44	0.47	0.44	0.07	0	0.35	0.34
	2081-2100	0.16	0.33	0.41	0.24	0.52	0.49	0.5	0.49	0.1	0	0.35	0.34
SSP5-8.5	2021-2040	0.16	0.3	0.41	0.22	0.45	0.43	0.48	0.45	0.08	0	0.35	0.34
	2041-2060	0.14	0.3	0.4	0.23	0.45	0.43	0.46	0.43	0.07	0	0.35	0.34
	2061-2080	0.15	0.32	0.41	0.24	0.49	0.46	0.49	0.47	0.09	0	0.35	0.34
	2081-2100	0.15	0.34	0.42	0.24	0.51	0.49	0.51	0.51	0.13	0	0.35	0.34

The climate change scenarios were extracted from the EC-Earth3-Veg model (CMIP6) by ArcGIS 10.5. The selected scenarios include SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, covering periods 2021 - 2040, 2041 - 2060, 2061 - 2080, and 2081 - 2100.

The observed, simulated, and predicted data were prepared to meet the input requirements of the CMhyd model. A linear method was used for calibrating the scenario data. The adjusted maximum temperature, minimum temperature, and rainfall data at the meteorological stations are illustrated in Figures 6 and 7. These calibrated datasets were used to project detailed irrigation demands for various crops in the Ba River basin.

The predicted results indicate that the maximum temperature, minimum temperature, and average monthly rainfall at the meteorological stations exhibit complex variations across emission scenarios, making it challenging to identify trends. Therefore, managing and utilizing water resources in the Ba River basin in the future is not straightforward.

3.4. Predicted irrigation water requirement under CMIP6 climate change scenarios

Using the CMIP6 climate change scenarios SSP1-2.6, SSP2-4.6, SSP3-7.0, and SSP5-8.5, and the calculation periods of 2021 - 2040, 2041 - 2060, 2061 - 2080, and 2081 - 2100, the research calculated the irrigation water requirement for crops in the four sub-basins. After detailed calculations of irrigation water requirements for 9 crops in sub-basins 1, 12 crops in sub-basin 2, 11 crops in sub-basins 3 and, 7 crops in sub-basin 4, we summarized the irrigation water demand for 1 ha of crop area in the sub-basins. Due to the varying crop structures among the sub-basins (Table 2) and the differing irrigation water requirements of each crop, the irrigation water requirement also varies significantly among the sub-basins. The results of these calculations are presented in Tables 4.

Based on the calculation results, it appears that in the future, the irrigation water requirements across different periods will show complex variations. However, the general trend is an increase towards the

end of the 21st century and a rise according to the emission scenarios. Except for October, where the irrigation water requirement is 0, the irrigation water requirement in other month ranges from 0.07 to 0.38 l/s/ha in sub-basin 1; from 0.01 to 0.37 l/s/ha in sub-basin 2; from 0.02 to 0.36 l/s/ha in sub-basin 3; and from 0.06 to 0.52 l/s/ha in sub-basin 4. May, June, July, and August are the periods with the highest water requirements in the basin. Compared to the current irrigation water requirements, the irrigation water requirement in the sub-basins is projected to increase. The increase in irrigation water requirement across different periods and scenarios ranged from 19.5 % to 45.7 % in sub-basin 1, 4.7 % to 31.3 % in sub-basin 2, 27.6 % to 66 % in sub-basin 3, and 12.1 % to 30.8 % in sub-basin 4.

The water requirement during the dry season, from January to August, will be very high in the future and is expected to increase in sub-basin 4. Currently, sub-basin 4 has the highest irrigation water requirements among the four sub-basins. Although the rate of increase in irrigation water requirements in sub-basin 4 was not the highest, it remained the highest among the four sub-basins. Rice continues to have the highest water requirement in the basin, with the peak requirement occurring in the late dry season in the lower part of sub-basin 4. Sub-basin 4 had over 20 % of its cultivated area planted with rice, making it the area with the largest proportion of rice fields in the basin. The period with the highest water requirement coincides with the growth period of the summer-autumn rice. With the dry season extending up to 8 months, the regulation of upstream water extraction facilities has a significant impact on crop development in the lower basin.

The Ba River basin has a large annual cultivated land area of 31 - 34 % of the total basin area (excluding forest area), so the leaching of fertilizers and pesticides can affect the soil environment (Dhaouadi et al, 2023) and groundwater in the area (Paltineanu, 2021, 2022). Therefore, detailed research on irrigation solutions to protect water and soil environments in tropical river basins must be carried out as soon as possible. For example, sub-basin 4 in the lower Ba River basin may have potential risks of salinity, so drip irrigation processes can be developed for crops except rice. In fact, drip irrigation has been proposed in the lower reaches of many large rivers such as the Yellow River basin, China (Lan et. Al, 2024).

4. CONCLUSIONS

The research assessed irrigation water requirements in the Ba river basin under varying climate conditions. The research applied the CROPWAT 8.0 model as the primary tool, complemented by ArcGIS software and the CMhyd model. This integrated approach proved effective in calculating and predicting irrigation water demands in tropical river basins. Climate data from the CMIP6 model were utilized as input scenarios to forecast irrigation needs for various crops within the basin.

In general, irrigation water requirements fluctuate greatly between the rainy and dry seasons, as well as between sub-basins in tropical river basins. This makes it difficult to allocate water resources to these river basins. The calculation results indicate that sub-basin 4 is the most water-scarce area in the basin. In the future, owing to the impact of climate change, the water requirements across all four sub-basins are predicted to increase. Although it is not the sub-basin with the highest overall increase in water requirement, sub-basin 4 showed significant increases in water requirement during the dry season from May to August, particularly for rice cultivation.

The calculated irrigation water requirements for different crops as well as for the sub-basins provide a scientific basis for water allocation in the basin, especially for managing water resources during dry season. In the context of climate change, the results also indicate that as water resources in the lower basin decline owing to increased industrial development, urbanization, and tourism, the requirement for water for agriculture will become increasingly challenging. Therefore, more detailed studies on crop structure in sub-basin 4 are recommended to ensure sustainable economic development in the Ba River basin. Furthermore, economic calculations are needed in national planning to determine the effective crop structure for each individual river basin. In addition, detailed research on irrigation solutions must be carried out as soon as possible.

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