Projecting the Impact of Human Activities and Climate Change on Water Resources in the Transboundary Sre Pok River Basin

Abstract

This study aims to project the compound impacts of climate change and human activities, including agriculture expansion and hydropower generation, on the future water availability in the Sre Pok River Basin. The five regional climate models (RCMs): ACESS, REMO2009, MPI, NorESM, CNRM were selected for the future climate projection under two scenarios i.e., RCP 4.5 and RCP 8.5. Our results reveal that the future annual rainfall is expected to decrease by 200 mm whereas the average temperature is expected to increase by 0.69°C to 4.16°C under future scenarios. The future water availability of Sre Pok River Basin was projected using soil and water assessment tool (SWAT). Next, the CROPWAT model was used to examine the irrigation water requirement and the HEC-ResSim model to simulate the hydropower generation of Buon Tuar Sarh reservoir. The future simulation indicates the decrease in future water availability, increasing demand for irrigation water and decreases in hydropower generation for the future periods. The irrigated areas are increases from 700 ha to 1500 ha as per the provincial development plan. This study also examines the present and future drought conditions of Sre Pok River via streamflow drought index (SDI). Our results expect to contribute toward supporting the planning and management of water resources for agriculture and to efficiently cope with drought conditions in the studied basin and beyond.

Keywords: climate change, human activities, SDI, SWAT, Sre Pok, Transboundary basin

1. Introduction

Hydrological cycles and processes are constantly shifting because of climate change impacts on human activities in many parts of the world (Huntington, 2006; Evers & Pathirana, 2018). The climate change-driven changes in precipitation and temperature alter the hydrological cycles that, in turn, affects the streamflow, water balance and quality (Norman, 2009). During the last past decades, climate change impacts and intensive human activities, rapid population growth, urbanization and economic development have resulted in sharp increases in water, energy and food demands which accelerates the pressures on land and water resources across the globe (Aghsaei et al., 2020). Human activities such as land clearing for agriculture, housing, other land-use practices, water diversions, reservoir/dam construction, and river sand mining have increased in many river basins, utilizing the natural features of river basins. (Sirisena et al., 2021).

The human activities and global climate changes have inflicted extreme impacts on global hydrology and water resources which results in significant floods, drought, degradation in water quality and quantity, water scarcity and many more (Renaud et al. 2015; Xu et al., 2018; Zhang et al., 2018). The impact of global climate change is visible all over the world and mostly in the Southeast Asia region (Yang et al., 2017, Pan et al., 2018; Zhang et al., 2019; Poelma et al. 2021). The massive Mekong region and its tributaries are home to both a dynamic hydro-ecological system and large potential hydropower. The excessive energy demand and rapid regional growth have led to the construction of various dams in mainstream and tributaries (Piman et al., 2013). The Mekong River basin's tributaries flow through Vietnam, which has been identified as one of the ten countries most affected by climate change between 1997 and 2016 (Eckstein et al., 2017). Along with climate change, rapid population growth, agricultural development, urbanization, reservoirs/dam constructions have significantly affected the availability of water resources in Vietnam (Huyen et al., 2017). With a long coastline and diverse topography from South to North, Vietnam is one of the most disaster-affected countries in the Western Pacific. Heavily storms and floods lead to human and economic losses. A rapidly growing population and urbanization are a threat to the natural resources of Vietnam, increasing greenhouse gas. Furthermore, Vietnam is projected to severely suffer from climate change for the next 30 years (GFDRR, 2011). Most studies are related to climate change in Vietnam, the impact of climate change on hydrology based on the greenhouse gas emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC 2000) through Regional Climate Models (RCMs) (Trang et al., 2017; Hoan et al., 2020). However, there are only a few studies concerning the combined impact of climate change and human activities on the future water resources in Vietnam.

This study focuses on the Sre Pok basin, which is the sub-basin of the 3S (Sesan, Sre Pok and Sekong), a tributary of the Mekong River. The Sre Pok River Basin straddles two countries of Vietnam and Cambodia. The total area of the Sre Pok River Basin is 30,965 km², of which 18,000 km² belong to Vietnam. So, the sustainability of the Sre Pok River Basin is closely related to the lives of millions from both Vietnam and Cambodia. The Government of Vietnam (2006) identified a number of critical issues for water resource management in the basin, ranging from hydrological variability such as floods and droughts to environmental degradation, overexploitation of groundwater, and water use conflicts, among other transboundary issues. So far, the current understanding of the Sre Pok River Basin is only limited to climate change impact on hydrology (Huyen et al.,2017, Trang et al., 2017). However, a comprehensive analysis of the impact of climate change and human activities on water resources is essential to enable more efficient, sustainable water resources development and suitable adaptation strategies in this region. This study aims to quantify the impact of climate change and human activities like agriculture development, hydropower generation for the future water availability in the Sre Pok River Basin, Vietnam.

The specific objectives of this study are to 1) project the future climate under RCP 4.5 and RCP 8.5 scenarios; 2) project and estimate the future water availability, future hydropower generation, the demand of irrigation water under RCP 4.5 and RCP 8.5 scenarios; and 3) estimate the drought index based on the impact of climate change, hydropower generation and irrigation expansion. This study is important in the case of the Sre Pok River Basin and Vietnam since the study area is extremely vulnerable to climate change and many proposed dam constructions which can affect the biodiversity and habitat of the river basin (Hoan et al., 2020). Finding from this study should provide a better understanding of the impact of climate change and human activities on water

resources. The results obtained in the study are expected to help water managers, researchers to understand the insights into the influence of human activities on the drought in the study area.

2. Material and Methods

2.1 Study area: The Sre Pok River Basin

The Mekong River Basin has many tributaries, among them Sre Pok River Basin is a major tributary which flows through two countries Cambodia and Vietnam with an area of 12,780 km² in Cambodia and 18,162 km² in Vietnam. The SrePok River Basin in the lower Mekong includes Dak Nong, Lam Dong, Dak Lak, Gia Lai, provinces of Vietnam and Stung Treng, Ratanakiri, Mondulkiri provinces of Cambodia (figure 1). In a northwest-to-southeast direction, the basin's elevation spans from 140 to 200 masl (meters above sea level). There are two types of seasons, i.e., wet, and dry seasons in the Sre Pok River Basin. The basin experiences 75–95% of the annual precipitation in the month of May to October (wet seasons). The mean annual temperature ranges from are 20 to 25°C.

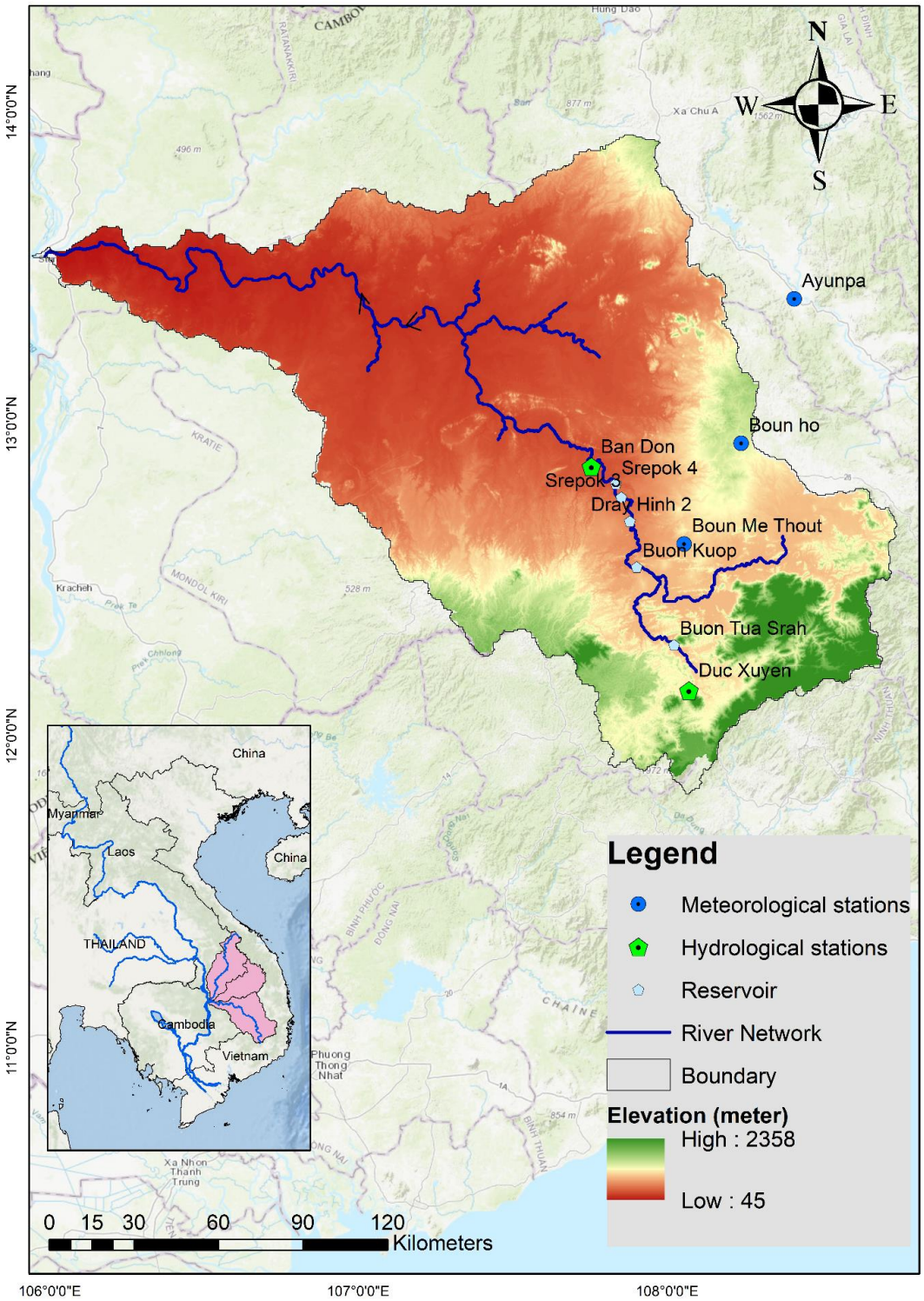

Figure 1: Location Map of the Sre Pok River Basin, Vietnam, and Hydro-meteorological stations with major reservoirs.

2.2 Hydro-Meteorological Data

For this study, Hydro-Meteorological data (i.e., discharge, rainfall, solar radiation, temperature, relative humidity, and wind speed) were obtained from the National Hydro-Meteorological Service of Vietnam. Hydropower information and Dam characteristics were obtained from Dak Lak DARD, Vietnam. Summary of the data source and the availability are given in table 1.

In this study, five regional climate models (RCMs) are selected, including precipitation and temperature output from 1971-2005 for historical scenarios and 2006-2099 for future scenarios. The models were used for the climate change projection of the Sre Pok River Basin. The details of the RCMs data are described in table 2.

Table 1. List of the data with duration and sources.

N°	Data	Time period	Frequency	Sources
1	Climate data (Observed data of temperature, rainfall, solar radiation, relative humidity, wind speed,)	1981-2015	Daily	National Hydro-Meteorological Service of Vietnam
2	Hydrological data (discharge)	1994-2015	Daily	National Hydro-Meteorological Service of Vietnam
3	RCM data (25kmx25km)	2005-2099	Daily	https://esgf-node.llnl.gov/search/esgf-llnl/
4	Topographic (DEM 30mx30m)	-	-	United States Geological Survey (USGS) Website
5	River network	-	-	FAO Website
6	Hydropower plan's location	-	-	The open development Mekong Website
7	Dam Characteristic (Dam height and length, Maximum, minimum, Normal water level, Reservoir capacity, dead storage)	-	-	Dak Lak DARD (Department of Agriculture and Rural Development)
8	Spillway Characteristic (Crest level, Discharge capacity)	-	-	Dak Lak DARD
9	Hydropower information (guide curve, installed power generation capacity)			Dak Lak DARD
10	Soil type (1kmx1km)	2000	-	MRC (Mekong river commission)
11	Land use/cover (1kmx1km)	2000	-	MRC
12	Irrigation data (current and future expansion)	2015, 2020	-	Dak Lak DARD, Daknong DARD
13	Crop calendar (rice crop)	2015	monthly	Dak Lak DARD, Daknong DARD

2.3 Methodological Framework

The future climate projection in the Sre Pok River Basin was carried out using three climatic variables i.e., rainfall, maximum temperature, and minimum temperature. The five RCMs were selected for projection of future climate for three future periods i.e., Near future 2020s (2010-2039), Mid-future 2050s (2040-2069) and far future 2070s (2070-2099) which were biased correct using linear bias correction. The SWAT model was used to simulate the water availability in the basin under future climatic conditions. The calibration and validation of the model was carried out on two discharge stations i.e., Duc Xuyen and Ban Don station. The calibration period is 1995-2001 and validation period is 2002-2005 for both Duc Xuyen and Ban Don station, respectively. The future water availability was estimated using model outputs under future climate scenarios for the period of near future (2011-2039) and mid-future (2040-2069). The CROPWAT model was used for the estimation of irrigation water requirements in Sre Pok River Basin. The HEC-Res Sim model was used in Boun Tua Sarh reservoir to estimate the future hydropower production. The methodological framework developed in this study is provided in figure 2.

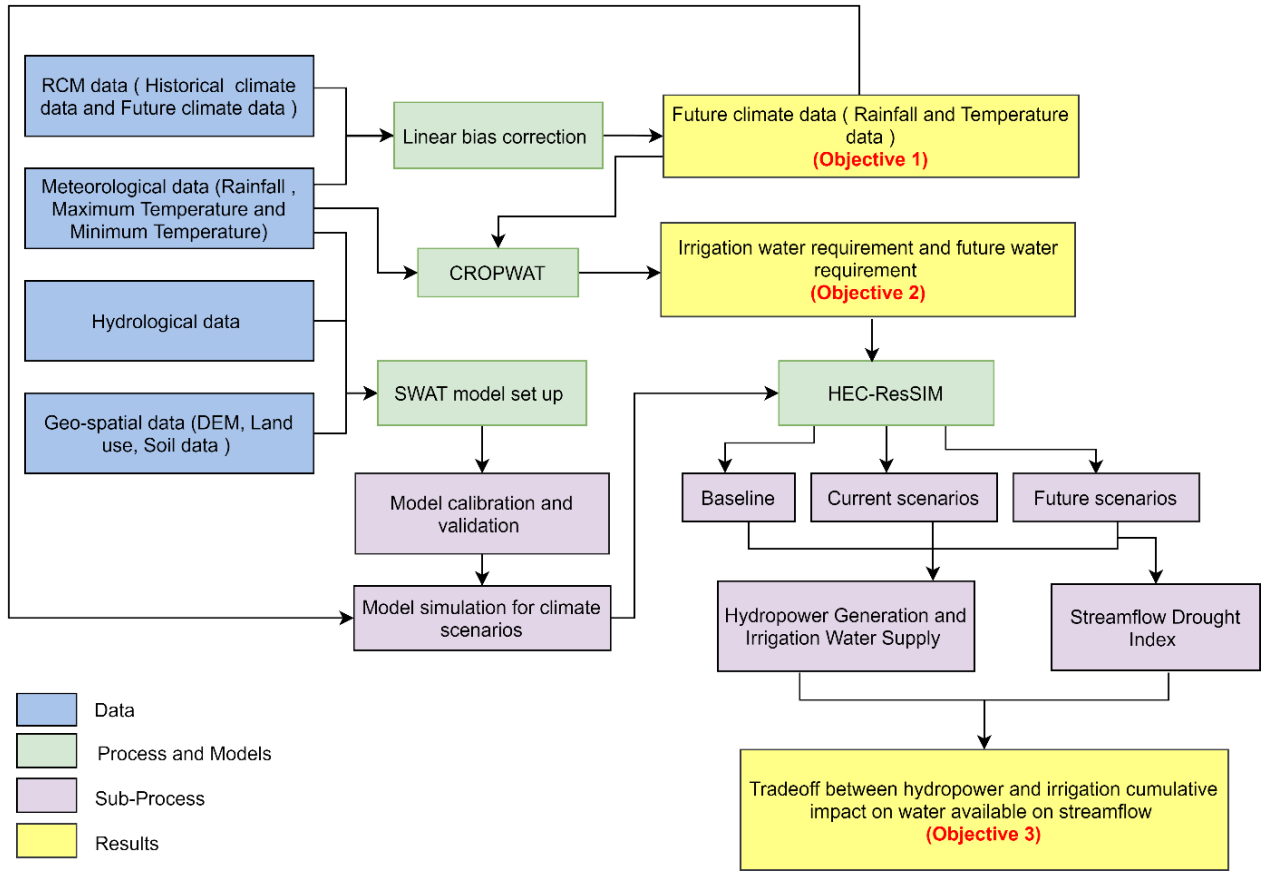

Figure 2: Overall methodological framework used in the study.

2.3.1 Climate Change Scenarios

The future climate and its impact on future water availability was projected using five RCMs under two representative concentration pathways (RCP) RCP 4.5 and RCP 8.5 scenarios. The Coordinated Regional Climate Downscaling Experiment (CORDEX) is the source of selected RCMs (table 2) (https://cordex.org/).

Table 2. List of RCMs and their information

Feature	RCM "Project: CORDEX"				
	ACCESS	**MPI**	**NorESM**	**CNRM**	**REMO2009**
Research Institute	Commonwealth Scientific and Industrial Research Organization, Australia	Commonwealth Scientific and Industrial Research Organization, Australia	Commonwealth Scientific and Industrial Research Organization, Australia	Commonwealth Scientific and Industrial Research Organization, Australia	Helmholtz-Zentrum Geesthacht, Climate Service Center Germany
Resolution	25kmx25km	25kmx25km	25kmx25km	25kmx25km	25kmx25km
Driving model	CSIRO-BOM-ACCESS1-CCAM	MPI-CCAM	NorESM1-M-CCAM	CNRM-CM5-CSIRO-CCAM	MPI-M-MPI-ESM-ECHAM5
Output variables	Temperature, precipitation, etc.	Temperature, precipitation, etc.	Temperature, precipitation, etc.	Temperature, precipitation, etc.	Temperature, precipitation, etc.
Scenario	Historical RCP 4.5 RCP 8.5	Historical RCP 4.5 RCP 8.5	Historical RCP 4.5 RCP 8.5	Historical RCP 4.5 RCP 8.5	Historical RCP 4.5 RCP 8.5
Data set coverage year	Historical: 1971-2007 RCP 4.5: 2006-2099 RCP 8.5: 2006-2099	Historical: 1971-2007 RCP 4.5: 2006-2099 RCP 8.5: 2006-2099	Historical: 1971-2007 RCP 4.5: 2006-2099 RCP 8.5: 2006-2099	Historical: 1971-2007 RCP 4.5: 2006-2099 RCP 8.5: 2006-2099	Historical: 1971-2007 RCP 4.5: 2006-2099 RCP 8.5: 2006-2099
Source	"https://esgf-index1.ceda.ac.uk/search/esgf-ceda/, https://cordex.org/ "				

The Linear bias correction method was applied for bias correction, to reduce the error characteristics of the RCMs. The linear bias correction method depends upon the scaling factor of differences between the observed and historical data. The observed climate data from the National Hydro-Meteorological Service of Vietnam was used to correct the five RCMs. Data from five rain gauges were used for correcting the rainfall and three temperatures stations were used for correcting the maximum and minimum temperatures. The correlation coefficient (R) was used to evaluate the performance of bias correction. The performance evaluation was based on the baseline period of 1980-2005. The future climate was evaluated based on three future periods the Near future 2020s (2010-2039), Mid-future 2050s (2040-2069) and far future 2070s (2070-2099) under RCP 4.5 and RCP 8.5 scenarios.

2.3.2 Hydrological Model

The future water availability in the Sre Pok River Basin was project using SWAT model based on several climate change scenarios. The SWAT is a semi-distributed model that just requires the most basic data for model inputs like climate, land use, soil, and digital elevation model (DEM) (Arnold et al., 2012). The climate variables required are daily precipitation, minimum and maximum temperatures, relative humidity, solar radiation, and wind speed. The hydrological simulation is carried out using the water balance equation (Neitsch et al., 2011), as shown in equation 1:

$$SW_t = SW_{init} + \sum_{i=1}^{t} (R_{day}(i) - Q_{surf}(i) - E_a(i) - W_{seep}(i) - Q_{gw}(i)) \quad (1)$$

where SW_t is the final soil water content (mm), SW_{init} is the initial soil water content (mm), t is the time in days, $R_{day}(i)$ is the precipitation on day i (mm), $Q_{surf}(i)$ is the surface runoff (mm), $E_a(i)$ is the evapotranspiration (mm), $W_{seep}(i)$ is the percolation (mm) and $Q_{gw}(i)$ is the amount of baseflow (mm).

The study uses climate (daily precipitation, maximum and minimum temperatures) and hydrological data to calibrate and validate the models and future climate scenarios to assess the future water availability in the basin. The observed data from two discharge gauge stations i.e., Duc Xuyen and BanDon station were used for model calibration and validation. The calibration was carried out for the time period of 1995-2005 and validation from 2002-2005. Four parameters of statistical analysis were used for the SWAT model performance evaluation: percentage bias (PBIAS), coefficient of determination (R2), Nash-Sutcliffe efficiency (NSE).

$$PBIAS = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * 100}{\sum_{i=1}^{n} Y_i^{obs}}\right] \quad (2)$$

$$R^2 = \left[\frac{\sum_{i=1}^{n}(Q_{o,i} - \bar{Q}_o)(Q_{s,i} - \bar{Q}_s)}{\sqrt{\sum_{i=1}^{N}(Q_{o,i} - \bar{Q}_o)}\sqrt{\sum_{i=1}^{N}(Q_{s,i} - \bar{Q}_s)}}\right]^2 \quad (3)$$

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - Q_i^{mean})^2}\right] \qquad (4)$$

Table 3. Performance of a statistical performance indicator are classified as below. (Rauf et al., 2018). R2: Coefficient of Determination, NSE: Nash-Sutcliffe Efficiency, PBIAS: Percent Bias (x)

Classification of Performance	R2	NSE	PBIAS
Very Good	0.85–1.00	0.75–1.00	x< 5
Good	0.70–0.85	0.65–0.75	5 ≤ x< 10
Satisfactory	0.60–0.70	0.50–0.65	10 ≤ x< 15
Acceptable	0.4–0.60	0.4–0.50	
Unsatisfactory	R2 ≤ 0.4	NSE ≤ 0.4	x ≥ 15

2.3.3 Crop Water Requirement

The Land and Water Development Division of FAO developed a decision support tool known as CROPWAT (FAO). It was used to define the total crop water requirement for rice cultivation along with the downstream of the SrePok river basin under climate change conditions—the crop, soil and climate data required for the CROPWAT model. The climatic values required include total monthly precipitation (P), potential evapotranspiration (PET) and average maximum and minimum temperatures per month.

The crop water requirement is illustrated in the following equation (5).

$$ET_C = K_C \times ET_0 \qquad (5)$$

Where Kc is crop coefficient (dimensionless); ET_{C^c} is crop evapotranspiration under standard conditions (mm/day); ET_0 is reference evapotranspiration (mm/day) can be estimated by equation 5. Notice that K_c varies on the type of crops and cropping season.

The reference evapotranspiration is estimated using FAO Penman-Monteith (PM) equation. The equation is expressed as follows.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (6)$$

Where Δ is slope vapour pressure curve (kPa/°C); G is soil heat flux density (MJ/m2·day); R_n is net radiation at the crop surface (MJ/m2·day); e_s is saturation vapour pressure (kPa); e_a is actual vapor pressure (kPa); γ is psychrometric constant (kPa/°C); u_2 is the wind speed at 2 m height (m/s); T is mean daily air temperature at 2 m height (°C); CROPWAT is a program that uses FAO PM for calculating ET_0.

2.3.4 Reservoir Simulations

The HEC-ResSim is a widely used simulation model for the reservoir systems within basins. It is developed by the Hydrologic Engineering Center of the US Corps of Engineers (Klipsch and Hurst, 2013). The hydropower generation capacity of the Buon Tuar Sarh reservoir is anticipated using HEC-ResSim for the 2020s and 2050s under RCP 4.5 and RCP 8.5 scenarios. The impact of hydropower on the Sre Pok River Basin under climate change scenarios is also investigated in this study. The inputs for the model are baseline reservoir operation data, physical reservoir characteristics data, baseline power generation data, energy characteristics data, daily discharge projections from the SWAT model and operational data for different reservoir zones. Climate change has a considerable impact on reservoir-based hydropower since it has a direct impact on seasonal river discharge, which is necessary for hydropower generation (Shrestha et al., 2021). The baseline period of 2010 to 2018 is compared with the future period of the 2020s and 2050s for the analysis of the climate change impact on the Buon Tuar Sarh reservoir, hydropower generation and irrigation water supply. The hydropower generation is analyzed based on the two baseline scenarios, i.e., 700 ha and 1500 ha of rice.

2.3.5 Streamflow Drought Index (SDI)

Streamflow Drought Index (SDI) is developed by Nalbantis and Tsakirirs to analyze drought index based on the streamflow data (Nalbantis and Tsakirirs (2009)). It has been broadly applied to calculate and estimate the level of drought in the region (Linh et al., 2021). We used SDI to estimate the present and future drought conditions in the SrePok river basin. The monthly discharge data is the input to calculate SDI via the cumulative streamflow volumes $Q_{i,j}$ assumed available where i denotes the year and j denotes the month of this hydrological year. The total streamflow volume can be estimated by the following equation.

$$V_{mn} = \sum_{n=1}^{3p} Q_{i,j} \quad m = 1,2 \ldots . \quad n = 1,2 \ldots 12 \quad p = 1,2,3,4 \qquad (7) \quad \text{(Tabari et al. 2012)}$$

Where V_{mn} is the cumulative streamflow volume for the m-th hydrological year and the p-th reference period (p=1 for October–December, p=2 for October–March, p=3 for October–June, and p=4 for October–September). SDI is defined based on cumulative streamflow volumes V_{mn} for each reference period k of the m-th hydrological year as follows

$$SDI_{m,p} = \frac{v_{m,p} - \bar{v}}{s_p} \qquad (8) \quad \text{(Tabari et al. 2012)}$$

Where $\bar{v}$ and s_p are the mean and standard deviation of the cumulative streamflow volumes, respectively, for reference period k as these are estimated over a long period of time. The negative value of SDI indicates a hydrological drought while positive values indicate wet conditions. The value of SDI indicated five stages of hydrological drought which are ranging from 0 (non-drought) to -4 (extreme drought).

In this study, SDI was calculated in monthly basis using drought indices calculator software (DrinC) for both baseline scenarios for time of 2010 to 2018 and future scenarios for period of 2019-2039. There were two presents' scenarios i.e., a) current irrigation demand (700 ha) b)

irrigation demand increased to 1500 ha and two future climate scenarios under RCP 4.5 and RCP 8.5 c) current irrigation demand (700ha), hydropower operation and d) irrigation demand increased to 1500 ha, hydropower operation.

3. Results

3.1 Climate Change Projection Scenarios in Sre Pok River Basin

3.1.1 Future Rainfall and Temperature Projection

The future average annual rainfall is projected for the near future, mid-future and far future with scenarios RCP 4.5 and RCP 8.5 and compared with the baseline period (1981-2005). For the near future period the average rainfall is expected to decrease by 200 mm and 300 mm for the mid-future and far-future period for RCP 4.5 scenarios. In contrast, the average annual rainfall is expected to decrease by 400 mm for the near future and mid-future period for the RCP 8.5 scenario (figure 3). Most of the RCMs shows a decreasing trend of rainfall for future periods, but REMO2009 shows an increasing trend of rainfall by 100 mm for RCP 4.5 and 250 mm for the RCP 8.5 scenario.

The future average annual temperature is projected for the near future, mid-future and far future with scenarios RCP 4.5 and RCP 8.5 in comparison with the baseline period (1981-2005) at Buon Ma Thuot station and Pleiku station. Figure 3 shows the absolute change in average maximum temperature for future projection under RCP 4.5 and RCP 8.5 scenarios. The average maximum temperature will increase by 1℃ and 1.5℃ in near future and mid future period and 2℃ in the far-future period in RCP 4.5 scenarios. Whereas, for RCP 8.5 scenario, the maximum temperature will increase by 1℃ and 2℃ in the near and mid future period and 3℃ in the far future period. Similarly, the average minimum temperature is expected to increase by 1℃ and 2℃ in near future and mid future period and 2.5℃ in the far future under RCP 4.5 scenario. The average minimum temperature is expected to increase by 4℃ in the far future under RCP 8.5 scenario (figure 3).

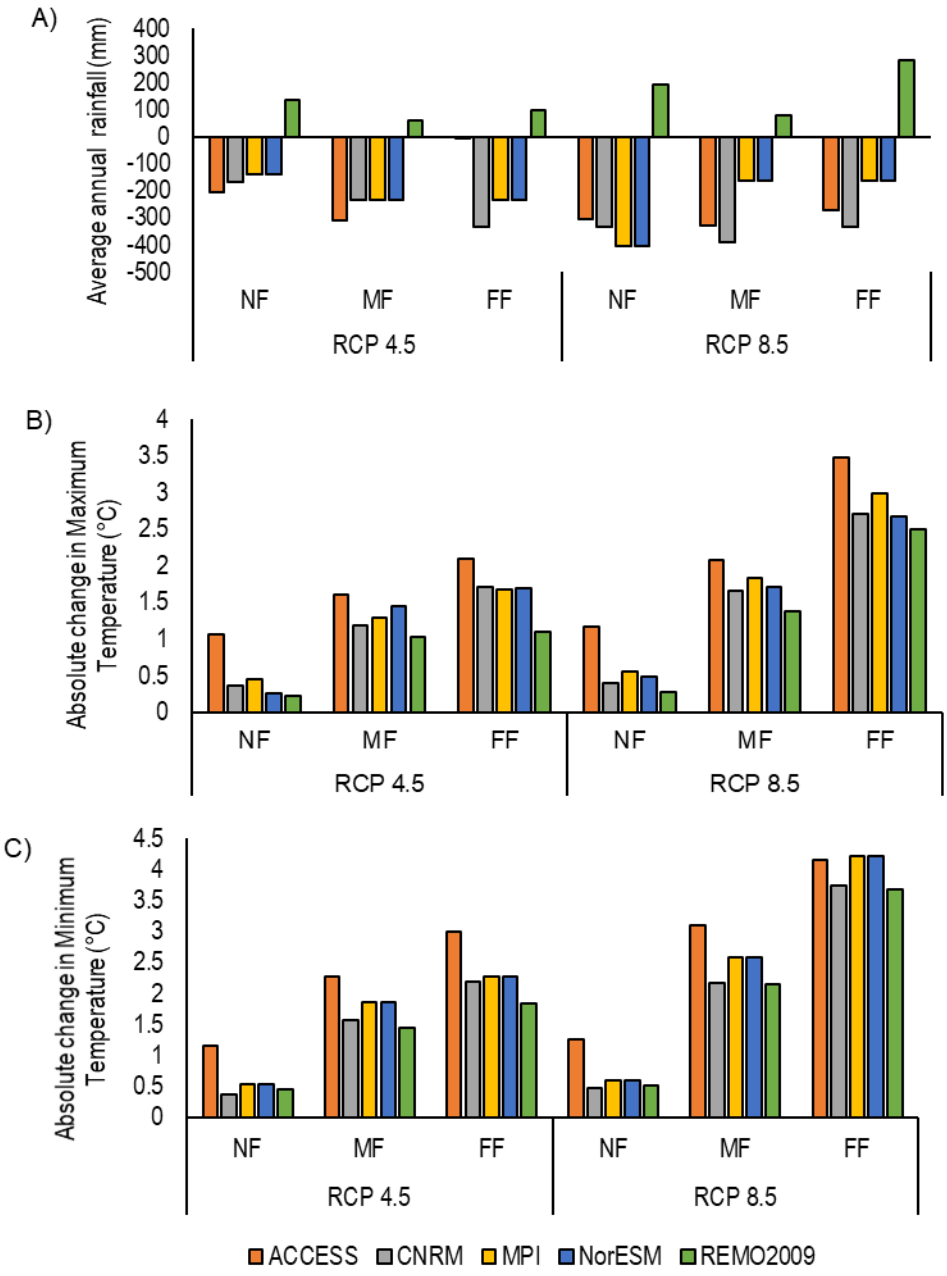

Figure 3: Absolute change in average A) rainfall B) maximum temperature C) minimum temperature for three future periods under RCP 4.5 and RCP 8.5 scenarios.

3.2 Performance of SWAT Model

The SLSUBBSN.hru , CH_K2.rte, OV_N.hru, are the most sensitive parameters for both discharge station when model was calibrated and validated for the 1995-2001 and the 2002-2005 period. The observed and simulated flow, including observed precipitation patterns, are plotted in figure 4 of both discharge stations

(Ban Don and Duc Xuyen), showing good agreement during calibration and validation periods. The model performance was satisfactory (table 4). The R^2 value ranged from 0.63-0.72 during the calibration and validation periods. The scatter plots in figure 4 indicates that the model effectively captured both low flow and high flow of both discharge station, but there are some abnormal peaks which were unable to captured effectively. During the calibration and validation periods, NSE value for both stations ranged from 0.5-0.72. The percentage bias (PBIAS) ranges between satisfactory and good during both calibration and validation periods. The validation period showed the hydropower construction and operation affected the normal flow regime in the Sre Pok River.

Table 4: SWAT Model performance evaluation for Ban Don and Duc Xuyen stations.

Stations	**R^2**		**NSE**		**PBIAS**	
	Calibration	**Validation**	**Calibration**	**Validation**	**Calibration**	**Validation**
Ban Don	0.72 (good)	0.62 (good)	0.72 (very good)	0.56 (satisfactory)	-4 (very good)	-13.4 (good)
Duc Xuyen	0.63 (good)	0.60 (good)	0.58 (satisfactory)	0.58 (satisfactory)	23.3 (satisfactory)	-3.7 (very good)

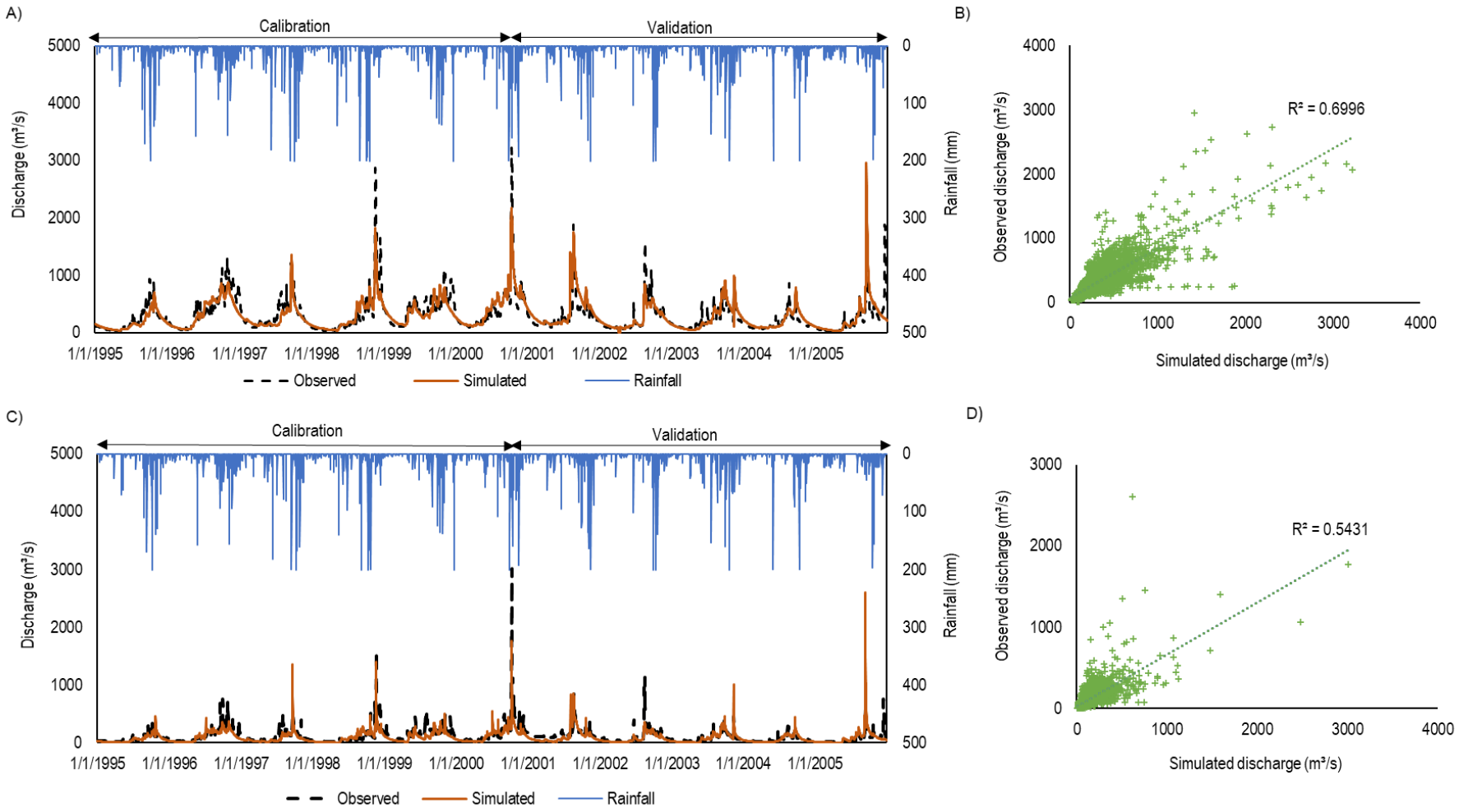

Figure 4: Observed and simulated discharge and rainfall at A&B) Ban Don station and C&D) Duc Xuyen station during SWAT calibration and validation.

3.2.1 Future Estimation of Water Availability

The average annual discharge for the baseline period (1995-2005) was 291 MCM. The projected future annual discharge for RCP 4.5 scenarios varied between 229 MCM and 297 MCM and for RCP 8.5 scenarios between 226 MCM and 306 MCM, respectively, as shown in table 4. In Sre Pok River Basin, the peak discharge usually occurs from June to August, with the minimum flow from February to April (Hoan et al., 2020). The peak discharge may occur from August to October, according to this analysis, though future availability patterns may alter. Water availability could be raised or decreased on an annual basis. The average future water availability might decrease under ACCESS, MPI, NorESM, CNRM climate models and increase under the REMO2009 climate model under both scenarios (table 5, figure 5). The decreased future water availability during cropping season can affect crop growth and leads to an increase the irrigation water requirement.

Table 5: Monthly water availability projections for five RCMs under both climate change scenarios for the period 2011-2069.

Month	Observed	Future water availability (MCM)									
		ACCESS		MPI		NorESM		CNRM		REMO2009	
	(MCM)	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Jan	179	172	157	159	146	150	135	172	150	183	188
Feb	101	111	113	107	100	100	96	109	102	126	129
Mar	74	85	83	81	74	85	78	83	76	96	96
Apr	83	68	68	78	70	65	72	83	72	76	81
May	156	107	124	155	129	89	124	135	127	111	142
Jun	219	198	255	229	190	190	188	185	185	240	290
Jul	251	257	268	259	218	218	233	229	231	342	336
Aug	429	353	351	310	264	281	303	342	347	491	456
Sep	514	478	434	489	460	445	478	447	401	580	600
Oct	548	432	382	497	528	512	451	482	480	609	619
Nov	500	375	325	410	366	386	332	401	377	432	447
Dec	436	252	253	238	220	231	218	246	227	275	286
Mean	**291**	**241**	**234**	**251**	**230**	**229**	**226**	**243**	**231**	**297**	**306**

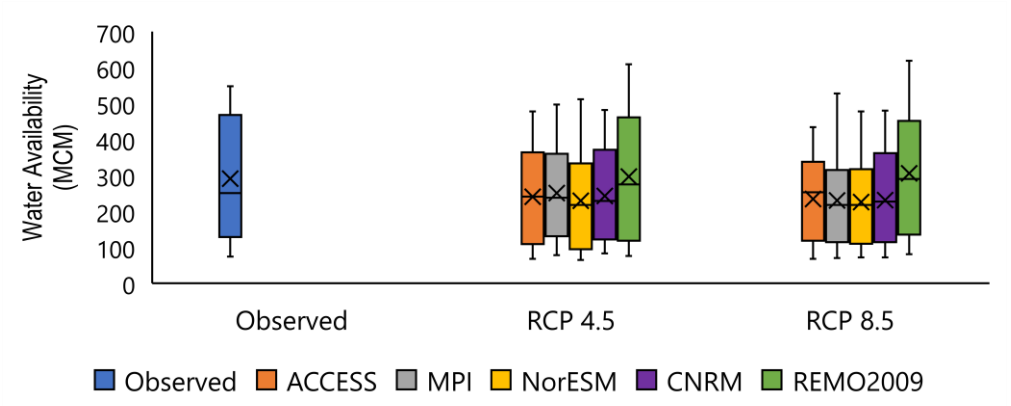

Figure 5: Boxplot distribution of Observed and future water availability (MCM) for RCP 4.5 and RCP 8.5 scenarios.

3.2.2 Climate Change Impact on Hydropower Production and Irrigation Water Supply

The Buon Tuar Sarh reservoir generate the annual hydropower of 328,474.6 MWh. When the irrigation is expanded from 700 ha to 1500 ha, hydropower production in dry season (January to March) is increases which increase the water demand for irrigation in baseline period. Overall, during the baseline period, the expansion of irrigation area from 700 ha to 1500 ha decreased the annual hydropower production from 328,474.6 MWh to 328,333.6 MWh. Similarly, climate change and irrigation expansion have an impact on future hydropower generation and irrigation water supply. The future hydropower generation is expected to decrease by more than 45% in the month of April and May for both future periods under RCP 4.5 and RCP 8.5 scenarios (figure 6). The future irrigation water supply is expected to decrease due to irrigation expansion and climate change for both future periods under RCP 4.5 and RCP 8.5 scenarios. The shortage of water supply to irrigated land is expected to occur during dry season (January-March and May). The shortage of water supply rate is increasing for the month of May from 1% to 13% when irrigation area is increased from 700 ha to 1500 ha for RCP 4.5 scenario. Whereas, for RCP 8.5 scenario the shortage of water supply rate is gradually increasing for every month of dry season from 1% to 17% (figure 7).

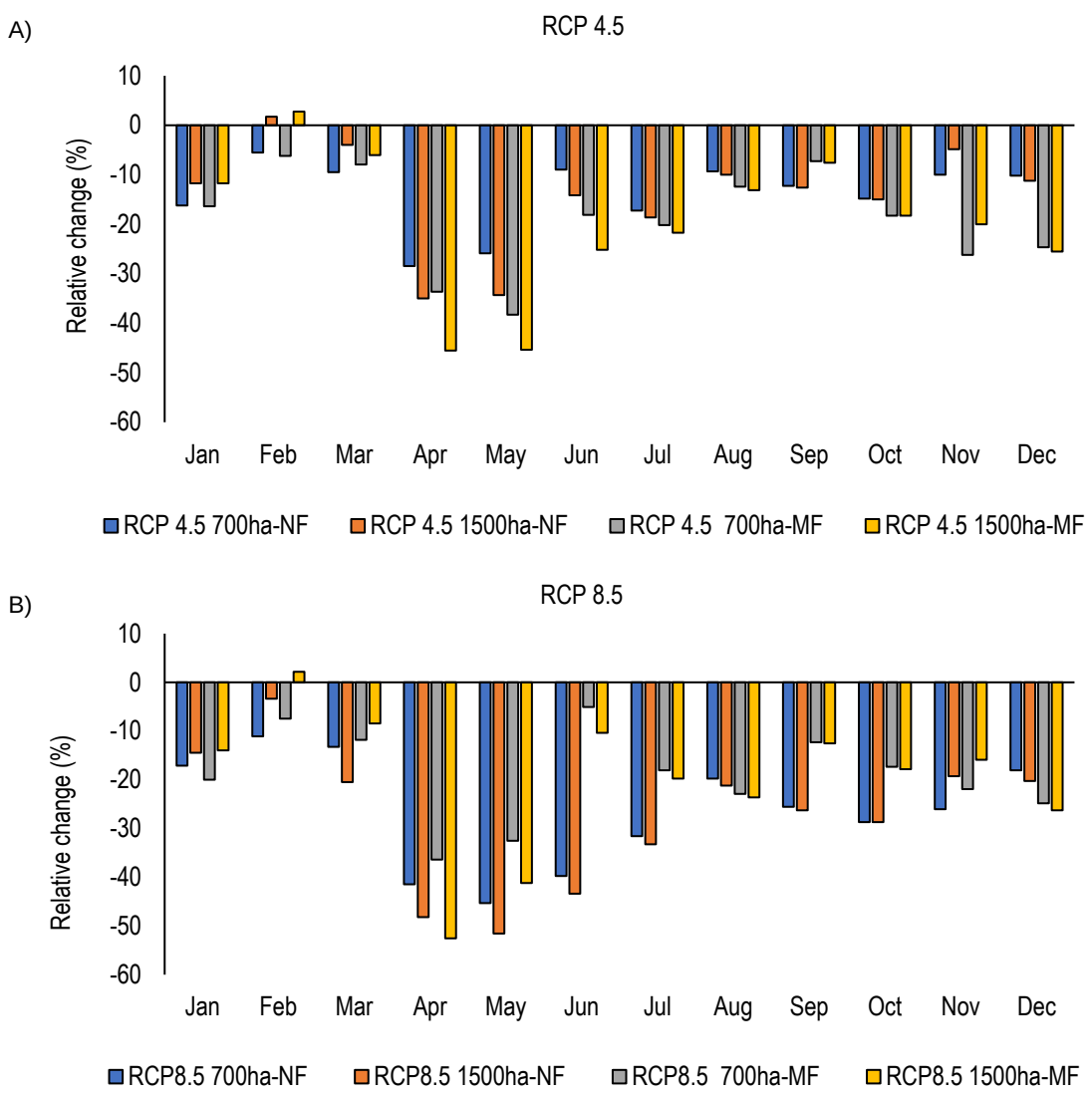

Figure 6: Relative change in monthly hydropower production for A) RCP 4.5 and B) RCP 8.5 scenarios in Buon Tuar Sarh reservoir.

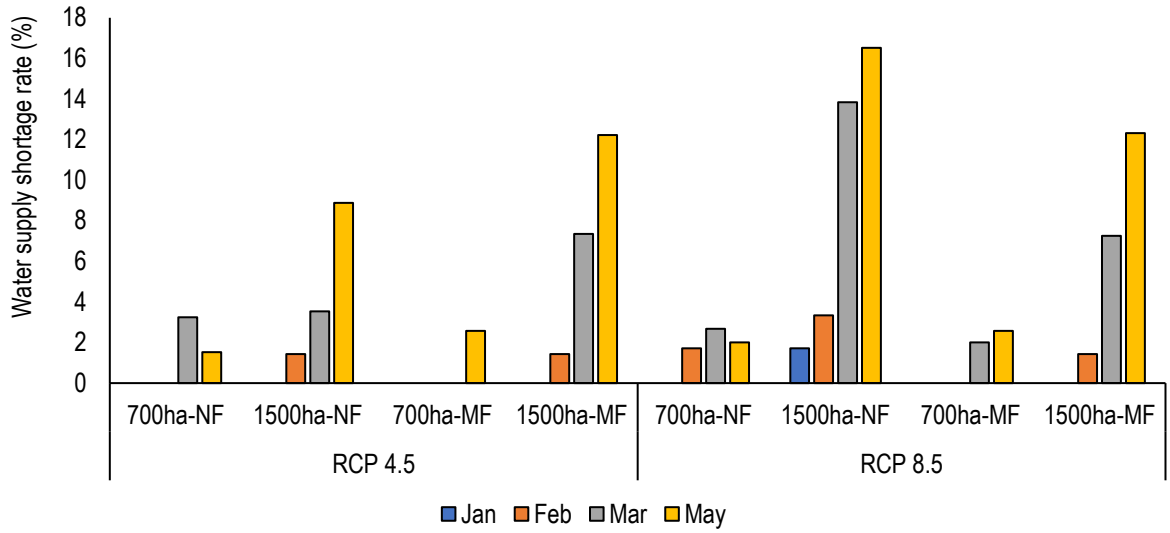

Figure 7: Irrigation water supply shortage rate at 700 ha and 1500 ha area under RCP 4.5 and RCP 8.5 scenarios.

3.3 Indicator Based Impact Assessment.

The future water availability estimated under climate change scenarios has projected that the availability of water in future periods will decrease by 19% as compared to the baseline period. There will be a shortage of water supply in future periods for irrigated areas. These results lead to estimation of drought at downstream of the Sre Pok River Basin. The drought was estimated using the streamflow drought index (SDI).

The calculated SDI has estimated no drought scenario for the current irrigation demand scenario at the downstream of Sre Pok River Basin. Whereas, for the irrigation demand increased to 1500 ha (scenario b) the basin would have experienced a severe drought from the 2014-2016 period with -2.04 SDI value (table 5). The increasing water demand might affect the water availability at the downstream of the river basin. The increasing water demand, shortage in irrigation water supply had changed drought situation from severe drought to extreme drought in the year of 2015-2016 (figure 8).

For future scenarios c and d, the basin is expected to experience the extreme drought condition with the highest SDI value (-3.49) for the period of 2029-2031 under RCP 4.5 scenario. For RCP 8.5, the highest

SDI is -3.9, and regardless of irrigation demands (700 ha or 1500 ha), combined with hydropower development, the basin will experience drought in 7 to 8 years for both the near future and mid future time period (figure 8). Sam (2019) also projects that the frequency; severity of drought will increase in the near future. When the irrigation area and hydropower operation increase the drought, the situation is expected to be more serious in the future period. However, water demand for irrigation is the main factor to increase serious drought downstream of the Sre Pok River Basin.

Table 6: SDI value showing extreme droughts of different scenarios for Sre Pok River Basin

Months	Baseline		RCP 4.5		RCP 8.5	
	700 ha	1500 ha	700 ha-HP	1500 ha-HP	700 ha-HP	1500 ha-HP
Oct-Dec	-1.77	-1.72	-1.66	-1.60	-0.88	-0.83
Jan-Mar	-0.77	-0.71	-3.02	-3.49	-3.90	-3.74
Apr-Jun	-1.97	-2.04	-2.19	-1.93	-1.96	-1.64
July-Aug	-1.55	-1.56	-2.19	-2.21	-1.52	-1.52

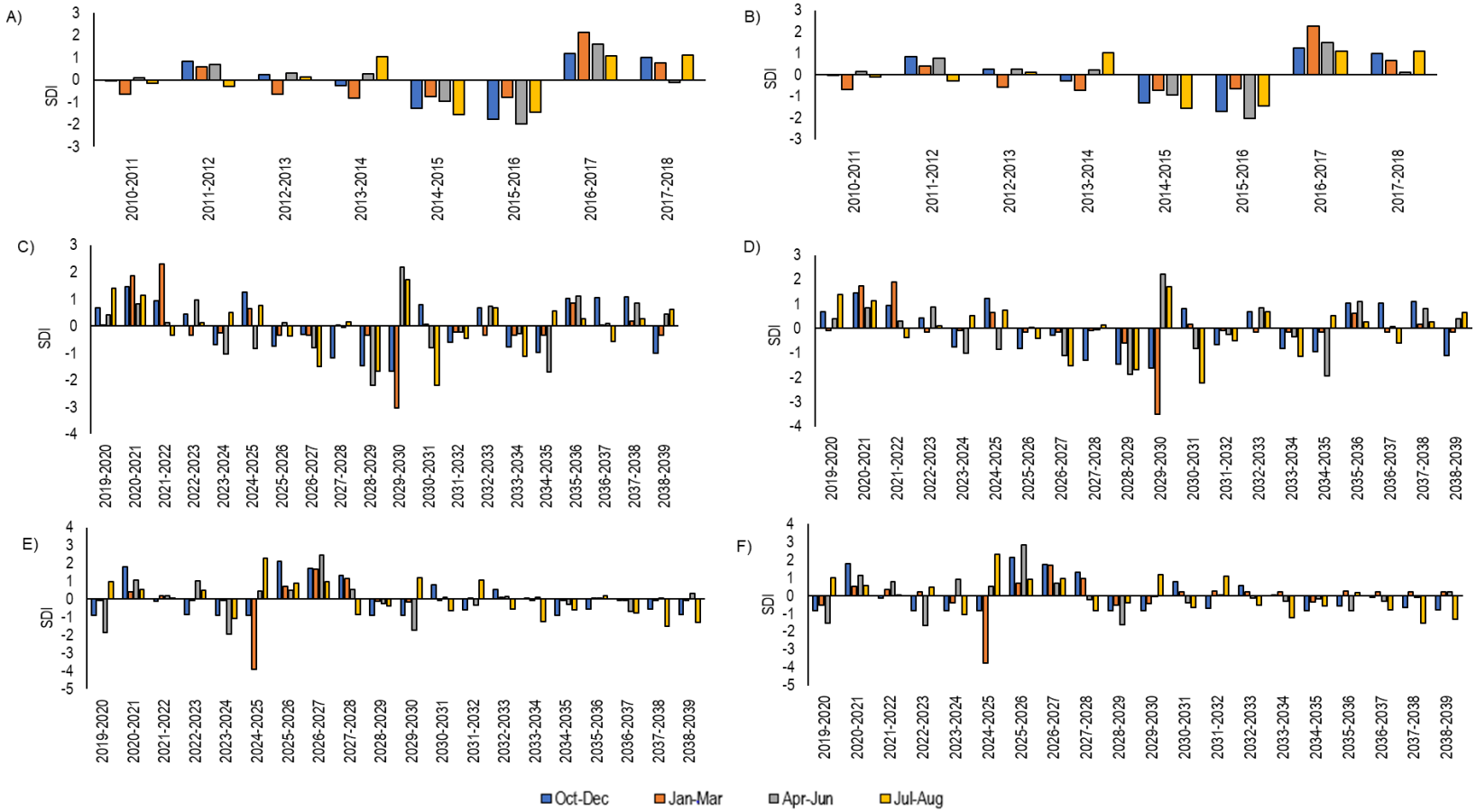

Figure 8: Streamflow drought index (SDI) values for baseline scenarios and future scenarios A) 700 ha of baseline scenario B) 1500 ha of baseline scenario C) 700 ha-Hydropower generation of RCP 4.5 scenario D) 1500 ha-Hydropower generation of RCP 4.5 scenario E) 700 ha-Hydropower generation of RCP 8.5 scenario F) 1500 ha-Hydropower generation of RCP 8.5 scenario

4. Discussions

4.1 Impact of Climate Change on Hydrology, Hydropower Generation and Water Availability

In Sre Pok River Basin, climate change has an impact on runoff mainly through variation in rainfall and temperature. The future rainfall is expected to decrease, whereas the future maximum temperature and minimum temperature is expected to increase. The rainfall plays an important role in the generation of runoff. As future rainfall is decreasing, the future runoff and water availability of the Sre Pok River Basin are decreasing. This study found out that the future water availability is expected to decrease by 10% to 21% as compared to observed runoff for the period of 1995-2005.

With the rapid growth of the economy and people, the basin has seen a variety of human activities including as urbanization, agricultural development, reservoir/dam construction, and deforestation, all of which have a significant impact on basin hydrology (Huyen et al., 2017, Pradhan et al., 2020;). The cultivated land area in the Sre Pok River Basin shows an annual increase from 1995-2010 and a relatively annual decrease from 2010-2015 (Gunawardana et al., 2021). In this study, the irrigation area is expanded from 700 ha to 1500 ha, which results in to increase in demand for irrigation water supply and a decrease in the runoff. The expansion of irrigation area is increasing hydropower production in the dry season but decreasing the annual hydropower generation from 328,474.6 MWh to 328,333.6 MWh. Similarly, climate change is also the factor affecting hydropower generation and irrigation water supply. This study projects that future hydropower generation is expected to decrease by more than 45% in the month of April and May. Similarly, the study also projects that the shortage of water supply to irrigated land will be increasing the month of May from 1% to 13% when irrigation area is increased from 700 ha to 1500 ha. Additionally, our findings show the impact of hydropower, expansion of irrigation leads to the shortage of water supply and drought in the Sre Pok river basin. From the impact assessment using streamflow drought index (SDI), the drought was estimated downstream of the Sre Pok River Basin. The drought was estimated for baseline scenarios

and future scenarios. The study projects that the Sre Pok River Basin will experience severe drought to extreme drought conditions in the near future periods.

4.2 Policy Implications and Future Outlooks

Our results can contribute to forming the basis for city-specific enhancement of water management, which shall provide useful implications for the climate change adaptation-related strategies and relevant action plans. The first of these is the joint transboundary action plan (2019-2024) between the Governments of Cambodia and Vietnam is to strengthen and promote sustainable water resources management, development of Sesan and Sre Pok river basins and Mekong delta regions. The main plan is to improve water security, minimize the impact of floods and drought and provide good quality water resource data and information (MRC 2019). The estimation of drought in this study directly helps to create and used as a monitoring tool to evaluate the present and future condition of drought in the Sre Pok River Basin. Furthermore, this study will help to provide good quality water resource data and information.

Mekong river commission is developing the Basin development strategy (BDS) 2021-2030, which strategy is to broaden the sustainable and reliable development opportunities with societal and environmental investment opportunities. Among various goals of the Plan is to mainstream climate-smart agriculture development, hydropower development, irrigation, and increase resiliency against drought and many more. These activities correspond to some findings like future hydropower generation, advantage, and disadvantage of expansion of irrigation area for present and future time period of the study and hence these findings can be used as one of the decision supports tools to help in the implementation of the master plan. Similarly, Annual irrigation water demand based on current plans to 2040 by MRC identify irrigation development opportunities to

support climate change adaptation, using climate-smart agriculture for improvement of food security and opportunities to expand irrigation areas for investment purpose. Therefore, our study found out that climate change has a great impact on the expansion of irrigation areas because it will increase the demand for water supply. Hence, this study can be useful for the estimation of future water demand for irrigation areas in the Mekong region.

According to 'food security' paradigm, most agricultural activities, agricultural and livelihood models, and irrigation plans are carried out in Vietnam (van Staveren et al., 2018). This study provides insight on the agricultural expansion and impact of agricultural expansion, the impact of climate change on agricultural expansion and the importance of agricultural water management in the Sre Pok River Basin. Nowadays, novel ecosystem-based agricultural models, hi-tech farming, smart agriculture have been increasingly adopted by local farmers of the Vietnam Mekong Delta (Park et al., 2021). It is recommended that Government should diversify the crops and new techniques, not only the agricultural areas. The Government should explore the different renewable sources, adopt ecosystem-based approaches to fulfil the future water demand, agricultural production in a sustainable manner (Loc et al.,2020; Yee et al.,2021).

4.3 Methodological Implications

This study builds upon the literature of climate change impact assessment, more specifically on water resources (Huyen et al., 2017;2018, Shrestha et al., 2021). Similarly, the implications of anthropogenic factors on the alterations of hydrological regimes of large riverine systems also attract considerable attention from the scientific community in recent years. Here we contribute for the first time a conceptual approach to explicitly quantify the compound effects of climate change and anthropogenic factors on hydropower capacity and irrigation. This study addresses the impact of human activities like the expansion

of irrigated areas, hydropower development which leads to intensification of the drought condition of the Sre Pok River Basin. The Sre Pok River Basin is a transboundary river basin between Vietnam and Cambodia, and the problem addresses by this study will be helpful for both countries to plan and implement different climate change adaptation strategies, drought management practices, irrigation management practices. In recent years, Vietnam has faced water scarcity and loss of agricultural production due to severe and prolonged droughts (FAO, 2016). Hence, our study projected that the people would face severe drought to extreme drought conditions by 2050 and show the influence of climate change on water resources. This methodology can be adapted for different climate change studies, drought assessments, human activities assessments by researchers, climate scientists, hydrologists, irrigation experts, policymakers, and stakeholders and many more.

Furthermore, this methodological framework can be a practical guideline for future studies regarding climate impact assessment, drought assessment, hydrology assessment many more. This methodology adapted only one indicator (SDI) to show the impact of human activities on water resources, but for future study, different indicators like water stress indicators, drought indicators and many others can be adapted. This methodological framework can be enhanced using Coupled Model Intercomparison Projects, Phase Sixth (CMIP6) climate models and shared socio-economic pathways (SSP) scenarios which will provide different mitigation and adaptation approaches to improve the different impact of human activities on water resources.

5. Conclusions

This study investigated the changes in streamflow, hydropower generation, droughts under the impact of climate change and human activities in the Sre Pok River Basin, Vietnam. The research used the five regional climate models (RCMs), i.e., ACCESS, MPI, NorESM, CNRM, REMO2009, to project the future climate under RCP 4.5 and RCP 8.5 scenarios. The Sre Pok River Basin will become warmer in the future

as the daily average maximum and minimum temperatures rise, but rainfall decreases, affecting daily runoff. The simulated discharge was calibrated and validated with observed data from the Ban Don and Duc Xuyen hydrological station for the period of 1995-2005 with the coefficient of determination and Nash-Sutcliffe index attaining satisfactory levels. The future annual discharge for both RCP 4.5 and RCP 8.5 scenarios are in decreasing pattern as compared to the observed discharge. The future water availability pattern may change but the peak discharge of the Sre Pok River Basin occurs from August to October month. The results suggest that future water availability will decrease during the cropping season and can affect crop growth and increase water demand. The research also shows the impact of climate change on hydropower generation and irrigation water supply. The results project that hydropower production will decrease from 328,474.6 MWh to 328,333.6 MWh if the irrigation area is expanded from 700 ha to 1500 ha. The expansion of irrigation areas will increase the shortage of water supply gradually, especially in the dry season for future scenarios. Overall, the impact of climate change and human activities is influencing the drought condition of the Sre Pok River Basin. The drought characteristics in terms of frequency, severity and duration are projected to increase in the near future. The study's findings could help plan and manage water resources in this region through adaptation and mitigation methods to climate change's impact on water availability, hydropower generation, and drought characteristics. In general, this study is also particularly relevant for policies associated with agricultural planning in Sre Pok River Basin. The policymakers should suggest some sustainable plan for the development of agriculture despite high water demand in future.

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