Projecting the impact of human activities and climate change on water resources in the transboundary Sre Pok River Basin

Pragya Pradhan1 · Trang Thi Huyen Pham1 · Sangam Shrestha1 · Ho Huu Loc1 · Edward Park2

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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 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 increased from 700 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; Loc et al. 2021a; Park et al. 2020; Evers and Pathirana 2018). The climate change-driven changes in precipitation and temperature alter the hydrological cycles that, in turn, affect streamflow, water balance, and quality (Norman and Michel 2009). Over the 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 accelerate 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).

Human activities and global climate changes have inflicted extreme impacts on global hydrology and water resources which result in significant floods, drought, degradation in water quality and quantity, water scarcity, and many more (Renaud et al. 2015; Xu et al. 2018; Loc et al. 2017, 2021b; Park et al. 2022; Zhang et al. 2018). The impact of global climate change is visible all over the world, with Southeast Asia being one of the most affected regions (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. 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 adversely affected by climate change between 1997 and 2016 (Eckstein et al. 2017). Along with climate change, other anthropological factors such as rapid population growth, agricultural development, urbanization, and reservoir/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-prone countries in the Western Pacific. Both natural disasters and anthropogenic stressors such as heavy storms and floods or a rapidly growing population and urbanization are noted to respectively increase the risk of human and economic losses, unsustainable exploitation of natural resources, and output of greenhouse gas in the country. Furthermore, existing projections suggest that Vietnam will continue to be severely impacted by climate change for the next 30 years (GFDRR 2011). Yet, while current studies related to climate change in Vietnam often look at the impacts of climate change on hydrology based on the greenhouse gas emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC) through Regional Climate Models (RCMs) (Trang et al. 2017; Hoan et al. 2020), there are only a few studies, however, that are concerned about the combined impact of climate change and human activities on the future state of water resources in the country.

This study, therefore, focuses on addressing this gap via a study of 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; and its sustainability is closely related to the lives of millions both in Vietnam and Cambodia. Tran et al. (2016) has previously 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. At the present moment, current knowledge surrounding the Sre Pok River Basin is mostly 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 resource development, and suitable adaptation strategies in this region. This study aims to quantify the impact of climate change and human activities like agriculture development and 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, and 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. A study of the Sre Pok River Basin and Vietnam is notably important as the study area is extremely vulnerable to climate change, which is further complicated by the many proposed dam constructions that can affect the biodiversity and habitat of the river basin (Park et al. 2022; Hui et al. 2022; Nguyen et al. 2020; Loc et al. 2021a; Hoan et al. 2020). Findings 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 and 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 is the Sre Pok River Basin, 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, respectively. The Sre Pok River Basin in the lower Mekong includes Dak Nong, Lam Dong, Dak Lak, and Gia Lai provinces of Vietnam and Stung Treng, Ratanakiri, and Mondulkiri provinces of Cambodia (Fig. 1). In a northwest-to-southeast direction, the basin’s elevation spans from 140 to 200 masl (meters above sea level). The basin has two types of seasons, i.e., wet and dry seasons, and experiences 75–95% of the annual precipitation in the month of May to October (wet seasons). The mean annual temperature ranges from 20 to 25 °C.

### 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) were selected, including precipitation and temperature output from 1981 to 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.
Fig. 1 Location map of the Sre Pok River Basin, Vietnam, and hydro-meteorological stations with major reservoirs
Table 1  List of the data with duration and sources

| No | 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 (25 km×25 km)                                              | 2005–2099   | Daily     | https://esgf-node.llnl.gov/search/esgf-llnl/                           |
| 4  | Topographic (DEM 30 m×30 m)                                         | -           | -         | 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, cischarge capacity)            | -           | -         | Dak Lak DARD                                                            |
| 9  | Hydropower information (guide curve, installed power generation capacity) | -           | -         | Dak Lak DARD                                                            |
| 10 | Soil type (1 km×1 km)                                               | 2000        | -         | MRC (Mekong river commission)                                           |
| 11 | Land use/cover (1 km×1 km)                                          | 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                                              |
| Feature                  | 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              | 25 km × 25 km               | 25 km × 25 km                | 25 km × 25 km               | 25 km × 25 km               | 25 km × 25 km        |
| 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 4.5                     | RCP 4.5                     | RCP 4.5              |
|                         | RCP 4.5                     | RCP 8.5                      | RCP 8.5                     | RCP 8.5                     | RCP 8.5              |
| Data set coverage year  | Historical: 1971–2007       | Historical: 1971–2007        | Historical: 1971–2007       | Historical: 1971–2007       | Historical: 1971–2007 |
|                         | RCP 4.5: 2006–2099          | RCP 4.5: 2006–2099           | RCP 4.5: 2006–2099          | RCP 4.5: 2006–2099          | RCP 4.5: 2006–2099   |
|                         | RCP 8.5: 2006–2099          | RCP 8.5: 2006–2099           | RCP 8.5: 2006–2099          | RCP 8.5: 2006–2099          | RCP 8.5: 2006–2099   |
| Source                  | "https://esgf-index1.ceda.ac.uk/search/esgf-ceda/, https://cordex.org/" |                             |                             |                             |                      |
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 (NF) 2020s (2010–2039), mid-future (MF) 2050s (2040–2069), and far future (FF) 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 were carried out on two discharge stations, i.e., Duc Xuyen and Ban Don stations. The calibration period is 1995–2001 and validation period is 2002–2005 for both Duc Xuyen and Ban Don stations, 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 CROP-WAT 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 Fig. 2.

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 RCMs were selected based on the literature reviews and current studies carried out in the region for the selection of RCM model and projection of future climate (Trang.

Fig. 2 Overall methodological framework used in the study
et al. 2017, Sam et al. 2019). The Coordinated Regional Climate Downscaling Experiment (CORDEX) is the source of selected RCMs (Table 2) (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 on 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 projected using a SWAT model based on several climate change scenarios. The SWAT is a semi-distributed model that primarily 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 was carried out using the water balance equation (Neitsch et al. 2011), as shown in Eq. 1:

$$SW_t = SW_{init} + \sum_{i=1}^{t} (R_{day}(i) - Q_{surf}(i) - E_a(i) - W_{seep}(i) - Q_{gw}(i))$$  \hspace{1cm} (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, minimum and maximum 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 Ban Don 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 ($R^2$), Nash–Sutcliffe efficiency (NSE) (Table 3).

| Classification of performance | $R^2$       | NSE         | PBIAS       |
|------------------------------|-------------|-------------|-------------|
| Very good                    | 0.85–1.00   | 0.75–1.00   | $x < 5$     |
| Good                         | 0.70–0.85   | 0.65–0.75   | $5 \leq x < 10$ |
| Satisfactory                 | 0.60–0.70   | 0.50–0.65   | $10 \leq x < 15$ |
| Acceptable                   | 0.4–0.60    | 0.4–0.50    |             |
| Unsatisfactory               | $R^2 \leq 0.4$ | NSE $\leq 0.4$ | $x \geq 15$ |

$R^2$, coefficient of determination; NSE, Nash–Sutcliffe efficiency; PBIAS, percent bias ($x$)
2.3.3 Crop water requirement

The Land and Water Development Division of Food and Agriculture Organization (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 Sre Pok 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 Eq. (5).

\[
ET_c = K_c \times ET_0
\]

where \( K_c \) is the crop coefficient (dimensionless); \( ET_c \) is the crop evapotranspiration under standard conditions (mm/day); and \( ET_0 \) is the reference evapotranspiration (mm/day) which can be estimated by Eq. (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.

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

where \( \Delta \) is slope vapor pressure curve (kPa/°C); \( G \) is the soil heat flux density (MJ/m²-day); \( R_n \) is the net radiation at the crop surface (MJ/m²-day); \( e_s \) is the saturation vapor pressure (kPa); \( e_a \) is the actual vapor pressure (kPa); \( \gamma \) is the psychrometric constant (kPa/°C); \( u_2 \) is the wind speed at 2 m height (m/s); \( T \) is the mean daily air temperature at 2 m height (°C); and 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 Tsakiris to analyze drought index based on the streamflow data (Nalbantis and Tsakiris 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 (Tabari et al. 2013).

\[
V_{mn} = \sum_{n=1}^{3p} Q_{i,j} m = 1, 2 \ldots n = 1, 2 \ldots 12 p = 1, 2, 3, 4 \tag{7}
\]

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 (Tabari et al. 2013)

\[
SDI_{m,p} = \frac{v_{m,p} - \overline{v}}{s_p} \tag{8}
\]

where \( \overline{v} \) 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 (700 ha), 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 periods for the RCP 8.5 scenario (Fig. 3). Most of the RCMs show 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 Thoat station and Pleiku station. Most of the RCMs show increasing trend of future maximum temperature of average of 1 °C, but ACESS shows increasing trend of more than 2 °C. Figure 3 shows the absolute change in average maximum temperature for future projection under RCP 4.5 and RCP 8.5 scenarios. The ensemble of models shows that average maximum temperature will increase by 1 °C and 1.5 °C in near future and mid future period, and 2 °C in the far-future period in RCP 4.5 scenarios. Whereas, for RCP 8.5 scenario, the maximum temperature will increase by 1 °C and 2 °C in the near and mid future period, and 3 °C in the far future period. The future projection of minimum temperature shows increasing trend for most of RCMs, but ACESS and MPI show increasing trend of more than 4 °C. The ensemble of models shows that average minimum temperature is expected to increase by 1 °C and 2 °C in near future and mid future periods, and 2.5 °C in the far future under RCP 4.5 scenario. The average minimum temperature is expected to increase by 4 °C in the far future under RCP 8.5 scenario (Fig. 3).

3.2 Performance of SWAT model

The SLSUBBSN.hru, CH_K2.rte, and 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 periods. The observed and simulated flow, including observed precipitation patterns, is plotted in Fig. 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 to 0.72 during the calibration and validation periods. The scatter plots in Fig. 4 indicate that the model effectively captured both low flow and high flow of both discharge stations, but there are some abnormal peaks which were unable to be captured effectively. During the calibration and validation periods, NSE value for both stations ranged from 0.5 to 0.72. The percentage bias (PBIAS) ranges from unsatisfactory to 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.
Future estimation of water availability

The average annual discharge for the baseline period (1995–2005) was 291 million m$^3$ (MCM). The projected future annual discharge for RCP 4.5 scenarios varied between 229

Fig. 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

3.2.1 Future estimation of water availability

The average annual discharge for the baseline period (1995–2005) was 291 million m$^3$ (MCM). The projected future annual discharge for RCP 4.5 scenarios varied between 229
and 297 MCM and for RCP 8.5 scenarios between 226 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, and CNRM climate models and increase under the REMO2009 climate model under both scenarios (Table 5, Fig. 5). The decreased future water availability during cropping season can affect crop growth and lead to an increase in the irrigation water requirement.

### 3.2.2 Climate change impact on hydropower production and irrigation water supply

The Buon Tuar Sarh reservoir generates an annual hydropower of 328,474.6 MWh. When the irrigation is expanded from 700 to 1500 ha, hydropower production during the dry season (January to March) is increased, which in turn increases the water demand for irrigation in the baseline period. Overall, during the baseline period, the expansion of irrigation area from 700 to 1500 ha decreased the annual hydropower production from 328,474.6 MWh.

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**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) | 22.2 (unsatisfactory) | −3.7 (very good) |

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**Fig. 4** Observed and simulated discharge and rainfall at A and B Ban Don station and C and D Duc Xuyen station during SWAT calibration and validation.
Table 5  Monthly water availability projections for five RCMs under both climate change scenarios for the period 2011–2069

| Month | Observed (MCM) | ACCESS RCP 4.5 | ACCESS RCP 8.5 | MPI RCP 4.5 | MPI RCP 8.5 | NorESM RCP 4.5 | NorESM RCP 8.5 | CNRM RCP 4.5 | CNRM RCP 8.5 | REMO2009 RCP 4.5 | REMO2009 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            |
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 (Fig. 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 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% (Fig. 7).

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 that 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 and shortage in irrigation water supply had changed drought situation from severe drought to extreme drought in the year of 2015–2016 (Fig. 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 periods (Fig. 8). Sam (2019) also projects that the frequency and 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).

### 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. Future rainfall is expected to decrease, whereas future maximum
Fig. 7  Irrigation water supply shortage rate at 700 ha and 1500 ha area under RCP 4.5 and RCP 8.5 scenarios

Fig. 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

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

| Months    | Baseline 700 ha | Baseline 1500 ha | RCP 4.5 700 ha-HP | RCP 4.5 1500 ha-HP | RCP 8.5 700 ha-HP | RCP 8.5 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              |
temperature and minimum temperature are expected to increase. Rainfall plays an important role in the generation of runoff. As future rainfall is decreasing, likewise, future runoff and water availability of the Sre Pok River Basin are decreasing. This study discovers that future water availability is expected to decrease by 10 to 21% as compared to the observed runoff for the period of 1995–2005.

With the rapid growth of the economy and population, the basin has seen a variety of human activities including 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). Cultivated land area in the Sre Pok River Basin, for example, shows an annual increase from 1995 to 2010 and a relatively annual decrease from 2010 to 2015 (Gunawardana et al. 2021). In this study, the irrigation area has been expanded from 700 to 1500 ha, resulting in increased demand for irrigation water supply and a decrease in the runoff. The expansion of irrigation area has also increased the hydropower production in the dry season but decreased the annual hydropower generation from 328,474.6 to 328,333.6 MWh. Similarly, climate change is also another 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. Piman et al. (2013) reported that there will be a minor decrease in the hydropower energy production in the Mekong tributaries, i.e., Sre Pok, Sesan and Sekong (3S basins). Correspondingly, this study also projects shortages of water supply to irrigated land, which increases in the month of May from 1 to 13% when irrigation area is increased from 700 to 1500 ha. Additionally, our findings demonstrate the impact of hydropower and expansion of irrigation, and how they bring about water supply shortage 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. This finding likewise concurs with a previous study done by Sam (2019), which suggests that future water availability of Sre Pok River Basin is decreasing, accompanied by an increased severity, duration, and frequency of droughts in the near future period.

4.2 Policy implications and future outlooks

Our results seek to establish a basis for city-specific enhancement of water management and contribute useful implications for climate change adaptation-related strategies and relevant action plans. The findings can be used to support the efforts of the existing joint transboundary action plan (2019–2024) between the Governments of Cambodia and Vietnam, further strengthening and needs to promote sustainable water resources management and development in the Sesan and Sre Pok River Basins and Mekong Delta regions. As a key objective of this bilateral action 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 provided in this study directly helps to create and can be used as a monitoring tool (or subsequently create new tools) to better evaluate the present and future condition of drought in the Sre Pok River Basin. Moreover, this study will help to provide high quality and accurate water resource data and information.

The result of this study is also suited to support the ongoing formulations of the Mekong River Commission’s (MRC) Basin Development Strategy (BDS) 2021–2030 — a strategy to broaden the sustainable and reliable development opportunities with societal and
environmental investment opportunities. We note that an important goal within the master plan is to mainstream climate-smart agriculture development, hydropower development, irrigation, and increase resiliency against drought and many more. These activities, we suggest, correspond with some of the findings like future hydropower generation, advantage, and disadvantage of expansion of irrigation area for present and future time periods of this study, hence, opening possibilities for our results to be further explored and used as one of the decision supports tools to assist the implementation of the master plan. In addition, our study is able to support the MRC’s endeavors to identify irrigation development opportunities to support climate change adaptation, using climate-smart agriculture for the improvement of food security and opportunities to expand irrigation areas for investment purpose. As noted in our findings, climate change greatly impacts the expansion of irrigation areas due to it resulting in increased demand for water supply. For that matter, we propose that this study can be further appropriated for the estimating of future water demand for irrigation areas in the Mekong Region.

Finally, this paper can inform ongoing discussions surrounding the critical topic of global “food security.” Vietnam is a major agricultural producer globally, with many agricultural activities, agricultural and livelihood models, and irrigation plans (van Staveren et al. 2018). Moreover, it is noted that novel ecosystem–based agricultural models, hi-tech farming, and smart agriculture are increasingly and continually being adopted by local farmers of the Vietnam Mekong Delta (Park et al. 2022). The study’s findings on this agricultural expansion and its impacts in the region and how climate change consequently bears on these agricultural expansion trends and the importance of agricultural water management in the Sre Pok River Basin provide vital knowledge to further strengthen and manage the region’s food security and its policies. For example, we recommended that local governments and regulatory bodies also look to diversify crops and introduce new farming techniques, apart from merely focusing on the expansion of agricultural areas. Authorities should explore the different renewable sources and adopt ecosystem-based approaches to fulfil the future water demand and 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). It also surveys the implications of anthropogenic factors on the alterations of hydrological regimes of large riverine systems, which has garnered 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 and 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 addressed by this study will be helpful for both countries to plan and implement different climate change adaptation strategies, drought management practices, and irrigation management practices. In recent years, Vietnam has faced water scarcity and loss of agricultural production due to severe and prolonged droughts (FAO 2016). Our study projects that the people would face severe drought to extreme drought conditions by 2050 and reveals the influence of climate change on water resources in the study region. 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, and many more. While this methodology used in this paper has employed one indicator (SDI) to show the impact of human activities on water resources, future studies can be adapted to incorporate different indicators of varying levels of complexities such as water stress indicators and drought indicators, among others. This methodological framework can be also further enhanced using Coupled Model Intercomparison Projects, Phase Sixth (CMIP6) climate models and shared socio-economic pathways (SSP) scenarios that provide different mitigation and adaptation approaches to improve the different impacts of human activities on water resources.

5 Conclusions

This study investigated the changes in streamflow, hydropower generation, and 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, and 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 to 328,333.6 MWh if the irrigation area is expanded from 700 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. Policymakers should seek to formulate a sustainable plan for agricultural development taking into consideration high water demand in the future.

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References

Aghsaei H, Mobarghaee Dinan N, Moridi A, Asadolahi Z, Delavar M, Fohrer N, Wagner PD (2020) Effects of dynamic land use/land cover change on water resources and sediment yield in the Anzali wetland catchment, Gilan, Iran. Sci Total Environ 712:136449. https://doi.org/10.1016/j.scitotenv.2019.136449

Arnold JG, Moriasi DN, Philip W, Abbaspour KC, White MJ (2012) SWAT: model use, calibration, and validation trans. ASABE 55:1549–1559. https://doi.org/10.13031/2013.42263

Eckstein D, Kunzel V, Schafer L (2017) Global climate risk index 2018: who suffers most from extreme weather events? Weather Related Loss Events in 2016 and 1997 to 2016. Germanwatch e.V, Berlin

Evers J, Pathirana A (2018) Adaptation to climate change in the Mekong River Basin: introduction to the special issue. Clim Change 149(1):1–11

FAO (2016) ‘El Nino’ event in Vietnam: agriculture food security and livelihood needs assessment in response to drought and saltwater intrusion. Hanoi

GFDRR (2011) Vulnerability, risk reduction, and adaptation to climate change. World Bank Group, Washington, DC

Gunawardana SK, Shrestha S, Mohanasundaram S, Salin KR, Piman T (2021) Multiple drivers of hydrological alteration in the transboundary Srepok River Basin of the Lower Mekong Region. J Environ Manage 278:111524

Hoan NX, Khoi DN, Nhi PTT (2020) Uncertainty assessment of streamflow projection under the impact of climate change in the Lower Mekong Basin: a case study of the Srepok River Basin, Vietnam. Water Environ J 34(1):131–142. https://doi.org/10.1111/wej.12447

Hui, T. R., Park, E., Loc, H. H., & Tien, P. D. (2022). Long-term hydrological alterations and the agricultural landscapes in the Mekong Delta: Insights from remote sensing and national statistics. Environmental Challenges 100454

Huntington TG (2006) Evidence for intensification of the global water cycle: review and synthesis. J Hydrol 319(1):83–95. https://doi.org/10.1016/j.jhydrol.2005.07.003

Huyen NT, Tu LH, Tram VNQ, Minh DN, Liem ND, Loi NK (2017) Assessing the impacts of climate change on water resources in the srepok watershed, central highland of Vietnam. J Water Clim Chang 8(3):524–534. https://doi.org/10.2166/wcc.2017.135

Klipsch JD, Hurst MB (2013) HEC-ResSim reservoir system simulation user’s manualversion 3.1. US Army Corps of Engineers Institute for Water Resources Hydrologic Engineering Center (HEC). https://www.hec.usace.army.mil/software/hecressim/documentation/HECResSim_31_UsersManual.pdf

Linh VT, Tram VNQ, Dung HM et al (2021) Meteorological and hydrological drought assessment for Dong Nai River Basin, Vietnam under climate change. Mobile Netw Appl. https://doi.org/10.1007/s11036-021-01757-x

Loc HH, Diep NTH, Can NT, Irene KN, Shimizu Y (2017) Integrated evaluation of ecosystem services in prawn-rice rotational crops, Vietnam. Ecosyst Serv 26:377–387

Loc HH, Irene KN, Suwanarit A, Vallikul P, Likitwat F, Sahavacharin A, Sovann C (2020) Mainstreaming ecosystem services as public policy in Southeast Asia, from theory to practice. In: Mauerhofer V, Rup D, Tarquini L (eds) Sustainability and Law, Springer, Cham, pp 631–665

Loc HH, Van Binh D, Park E, Shrestha S, Dung TD et al (2021a) Intensifying saline water intrusion and drought in the Mekong Delta: From physical evidence to policy outlooks. Sci Total Environ 757:143919

Loc HH, Lixian ML, Park E, Dung TD, Shrestha S, Yoon YJ (2021b) How the saline water intrusion has reshaped the agricultural landscape of the Vietnamese Mekong Delta, a review. Sci Total Environ 794:148651

MRC, & World Bank, W. B. (2019) Joint transboundary action plan in the Sesan and Srepok River Basin and the Mekong Delta of Cambodia and Vietnam. April, 25 pp

Nalbantis I, Tsakiris G (2009) Assessment of hydrological drought revisited. Water Resour Manage 23:881–897

Neitsch AL, Arnold JG, Kiniry JR, Williams JR, Neitsch S, Arnold JG et al (2011) Soil and water assessment tool theoretical documentation version 2009, Texas Water Resources Institute. Texas A&M University, College Station
Nguyen QH, Tran DD, Dang KK, Korbee D, Pham LD, Vu LT, Luu TT, Ho LH, Nguyen PT, Ngo TTT, Nguyen DTK, Wyatt A, van Aalst M, Tran TA, Sea WB (2020) Land-use dynamics in the Mekong delta: From national policy to livelihood sustainability. Sustain Dev 28(3):448–467

Norman EP, Michel M (2009) Water quality degradation effects on freshwater availability: impacts of human activities. Water Int 25(2):185–193. https://doi.org/10.1080/02508060008686817

Pan Z, Ruan X, Qian M, Hua J, Shan N, Xu J (2018) Spatio-temporal variability of streamflow in the Huaihe River Basin, China: climate variability or human activities? Hydrol Res 49(1):177–193. https://doi.org/10.2166/hr.2017.155

Park E, Ho HL, Tran DD, Yang X, Alcantara E, Merino E, Son VH (2020) Dramatic decrease of flood frequency in the Mekong Delta due to river-bed mining and dyke construction. Sci Total Environ 723:138066

Park E, Loc HH, Van Binh D, Kantoush S (2022) The worst 2020 saline water intrusion disaster of the past century in the Mekong Delta: Impacts, causes, and management implications. Ambio 51(3):691–699. https://doi.org/10.1007/s13280-021-01577-z

Piman T, Cochrane TA, Arias ME, Green A, Dat ND (2013) Assessment of flow changes from hydropower development and operations in Sekong, Sesan, and Srepok Rivers of the Mekong Basin. J Water Resour Plan Manag 139(6):723–732. https://doi.org/10.1061/(asce)wr.1943-5452.0000286

Poelma T, Bayrak MM, Van Nha D, Tran TA (2021) Climate change and livelihood resilience capacities in the Mekong Delta: A case study on the transition to rice–shrimp farming in Vietnam’s Kien Giang Province. Clim Change 164(1):1–20

Pradhan P, Tingsanchali T, Shrestha S (2020) Evaluation of soil and water assessment tool and artificial neural network models for hydrologic simulation in different climatic regions of Asia. Sci Total Environ 701:134308. https://doi.org/10.1016/j.scitotenv.2019.134308

Rauf A ur, Ghumman AR (2018) Impact assessment of rainfall-runoff simulations on the flow duration curve of the Upper Indus river-a comparison of data-driven and hydrologic models. Water (Switzerland) 10(7). https://doi.org/10.3390/w10070876

Renaud FG, Le TTH, Lindener C, Guong VT, Sebesvari Z (2015) Resilience and shifts in agro-ecosystems facing increasing sea-level rise and salinity intrusion in Ben Tre Province, Mekong Delta. Clim Chang 133(1):69–84

Sam TT, Khoi DN, Thao NTT, Nhi PTT, Quan NT, Hoan NX, Nguyen VT (2019) Impact of climate change on meteorological, hydrological, and agricultural droughts in the Lower Mekong River Basin: a case study of the Srepok Basin, Vietnam. Water Environ J 33(4):547–559. https://doi.org/10.1111/wej.12424

Shrestha A, Shrestha S, Tingsanchali T, Budhathoki A, Ninsawat S (2021) Adapting hydropower production to climate change: a case study of Kulekhani Hydropower Project in Nepal. J Clean Prod 279. Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.123483

Sirisena TAJG, Maskey S, Bamunawala J, Ranasinghe R (2021) Climate change and reservoir impacts on 21st-century streamflow and fluvial sediment loads in the Irrawaddy River, Myanmar. Front Earth Sci 9(March):1–16. https://doi.org/10.3389/feart.2021.644527

Tabari H, Nikbakht J, Talaei PH (2013) Hydrological drought assessment in Northwestern Iran based on streamflow drought index (SDI). Water Resour Manage 27(1):137–151

Trang NTT, Shrestha S, Shrestha M, Datta A, Kawasaki A (2017) Evaluating the impacts of climate and land-use change on the hydrology and nutrient yield in a transboundary river basin: a case study in the 3S River Basin (Sekong, Sesan, and Srepok). Sci Total Environ 576:586–598

Tran T, Nguyen T, Huynh H, Mai K, Nguyen H, Phong H, Doan PY (2016) Climate change and sea level rise scenarios for Vietnam. Summary for Policymakers ER

van Staveren MF, van Tatenhove JPM, Warner JF (2018) The tenth dragon: controlled seasonal flooding in long-term policy plans for the Vietnamese Mekong Delta. J Environ Policy Plan 20(3):267–281. https://doi.org/10.1080/1523908X.2017.1348287

Xu Y, Wang S, Bai X, Shu D, Tian Y (2018) Runoff response to climate change and human activities in a typical karst watershed, SW China. PLoS ONE 13(3):e0193073. https://doi.org/10.1371/journal.pone.0193073

Yee JY, Loc HH, Poh YL, Vo-Thanh T, Park E (2021) Socio-geographical evaluation of ecosystem services in an ecotourism destination: PGIS application in Tram Chim National Park, Vietnam. J Environ Manag 291:112656

Zhang L, Nan ZT, Wang WZ, Ren D, Zhao YB, Wu XB (2019) Separating climate change and human contributions to variations in streamflow and its components using eight time-trend methods. Hydrol Processes 33(3):383–394. https://doi.org/10.1002/hyp.13331
Zhang Z, Wan L, Dong C, Xie Y, Yang C, Yang J, Li Y (2018) Impacts of climate change and human activities on the surface runoff in the Wuhua River Basin. Sustainability (Switzerland) 10(10):3405. https://doi.org/10.3390/su10103405

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