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Flow Regime Alteration under Regional Climate Models in Stung Chinit River Basin, Cambodia

Sokchhay Heng[1], Panha Hok[1*], Md. Mafizur Rahman[2], Norith Phol[1]

[1] *Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia*

[2] *Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh*

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Abstract: *This study aims to assess flow regime alterations under climate change scenarios in the Stung Chinit river basin, one among tributaries of the Tonle Sap Great Lake, Cambodia. Five bias-collected regional climate models (RCMs) under RCP4.5 and RCP8.5 using quantile mapping technique were employed into the Soil and Water Assessment Tool (SWAT) model to quantify changes in future hydrologic characteristic. Three future time horizons —the 2020s, 2050s, and 2080s were assessed in comparison with the baseline period. Based on individual and ensemble average RCMs, the result showed that the average temperature is expected to get warmer between 1°C and 2°C, especially in the 2080s under RCP8.5. The future rainfall indicated variability and an unclear direction, but the dry season rainfall is generally projected to increase for all three future time horizons. Despite this uncertainty, future river discharge at Kampong Thmar in the Stung Chinit basin is still expected to have excessive river discharge between 8% and 144%. This also implies that climate change will induce quite more frequent flood and fewer drought events because of rising in high flow (Q5) and low flow (Q95), respectively. These results will be useful for the Stung Chinit river basin planning, development, and management to cope with future climate change, climate variability and infrastructure development, and relevant implementation activities within the basin and also any future in-depth research.*

Keywords: Climate change; Flow regime; Regional climate models; Stung Chinit; SWAT model

1. INTRODUCTION

Climate change is believed to be one of the predominant challenges for mankind in the 21st century, which has resulted in immense adverse effects on human and natural systems around the world. Rising greenhouse emission to the atmosphere is likely to change hydrological cycles, particularly the growth of spatiotemporal variation in rainfall, and flow regime will plausibly fluctuate (IPCC, 2013). These alterations will be dissimilar in terms of topography, catchment size, and location (Vicuña et al., 2011). In Southeast Asia, Christensen (2013) and IPCC (2014) also reported that Cambodia has already been experiencing long-term changes in climate and is plausibly vulnerable and exposed to this impact due to its low adaptive capacity and resilience. In addition, water scarcity is very common problem in all catchments around the Tonle Sap Great Lake, particularly the Stung Chinit river basin. So, without proper and effective strategies and action plans, these problems will significantly heighten the instability of the economic growth, livelihoods, and well-being (Sreymom et al., 2015) because of infrastructure development, climate hazards, etc., which will put Cambodia under intense pressures to achieve the Sustainable Development Goals (SDGs) (MOWRAM, 2014). Phan Cao et al. (2017) reported that the magnitude of severe flood and droughts will occur more frequently in the future. However, to cope with any current issues and future challenges, understanding water availability is very indispensable with a reliable supporting tool (Phan Cao et al., 2017). Likewise, the Soil and Water Assessment Tool (SWAT) model, which is one among robust, systematic, and decision support tools, has been accepted and turned to use globally (Gassman et al., 2010) and part of the Mekong River Commission's toolbox. Also, to minimize some degrees of uncertainties associated with the climate projection, the quantile mapping technique is generally used and reliably performs to correct the bias of climate models (Miao et al., 2016). To date, many impact assessments on water resources have been conducted on river basins or regional scales as a result of changes in rainfall, temperature, and evapotranspiration (Nam et al., 2016).

Several researchers suggested that the temperature will get warmer in the future. However, unclear changes and directions are also found from the projected rainfall and river

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[*] Corresponding author: Panha Hok
E-mail: hokpanha8@gmail.com;
Tel: +855-10-288-384/+855-89-575-578

discharge based upon General Circulation Models (GCMs) and chosen downscaling techniques (Hoanh et al., 2011; Khoi and Hang, 2015; Kingston et al., 2011; Lauri et al., 2012; Västilä et al., 2010). Rising in the annual river discharges and rainfall are mostly identified from almost GCMs, but other GCMs illustrated opposite directions (Kingston et al., 2011; Lauri et al., 2012). Piman (2015) also concluded that the climate change in the 3S River Basin is potential to drop in the dry season flow between 6% and 24%, but predictions of the annual and river discharge are completely unsure. Similarly, Phan Cao et al. (2017) found that drought and severe floods in the Red river basin, Vietnam, tend to increase in the near future from multi climate models, especially the excessive flow can be expected between 25% and 30% in the late wet season. However, Oeurng et al. (2019) found that 11 basins surrounding the Tonle Sap Great Lake, Cambodia, are projected to drop in the mean annual flow under all three GCMs from 9% to 29% in the 2030s, 10% to 35% in the 2060s, and 7% to 41% in the 2090s. Q5 and Q95 are also expected to reduce in the future. Despite several studies on climate change impacts on streamflow within Southeast Asia, there are still limited studies considered employing multi-high-resolution climate models like regional climate models (RCMs). Also, to foresee future challenges governing water availability in the Stung Chinit river basin is needed for planning and managing future water resources to assure long-term sustainability.

In this study, hydrological responses of the Stung Chinit river basin to the individual and ensemble average RCMs in three future time horizons: near future (2020s), mid future (2050s), and far future (2080s), with respect to simulation for the baseline period from a sophisticated and robust hydrological model, will be carried out. This study will also provide updated information on the climatic and hydrological projection in comparison with previous studies to the NGOs, government (local and national), and policymakers for proper and sustainability planning, developing and managing water resources within the basin.

2. METHODOLOGY

2.1 General framework

The overall methodology of this study is illustrated in Fig. 1. Quality control and formatting of the climatic and hydrological data within the Stung Chinit river basin were performed and prepared for the hydrological model development. The SWAT model for the Stung Chinit river basin was developed with the warm-up (1994-1996), calibration (1997-2005), and validation (2006-2008) period. The manual or auto-sensitivity analysis (a range of ±30% of relevant default model parameters) was also conducted to identify most sensitive parameters to the model result (river discharge), so time-saving can be achieved. With several most sensitive parameters, the model calibration was performed using the sequential uncertainty fitting algorithm (SUFI-2) from the SWAT_CUP software. Also, the observed discharge at Kampong Thmar hydrological station from 1997 to 2008 was employed in this calibration and validation process. So, once the result was acceptable and reasonable, the calibrated and validated model was ready for generating future hydrology in the Stung Chinit river basin from the bias-corrected future climate scenarios from five RCMs under two emission scenarios. Finally, future climatic and flow regime analysis can be accomplished.

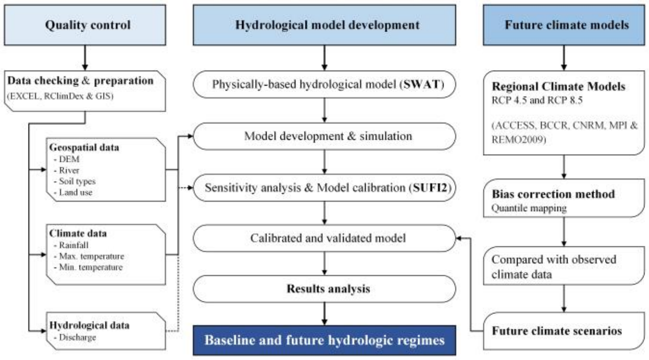

Fig. 1. General framework of methodology

2.2 Study area

The Stung Chinit river is one of the tributaries of the Tonle Sap Great Lake extending throughout the Cambodia’s central plains. This Great Lake has been playing a vital role in Cambodia and within the Lower Mekong Basin due to its complex hydrological and ecological systems. The basin area is 8,236 km^2. About 40% of the whole area is with elevation from 1 to 30 m and the highest elevation is 653 m. The Stung Chinit river drains from the North, flows down in South-West direction with a full length of 240 km and discharges into the Tonle Sap Great Lake (Fig. 2). The flow of this river is measured at the gauging station located at Kampong Thmar Bridge along National Road No. 6. A slight difference in the surface slope is noticeable during the wet and dry season; however, toward the downstream area, it becomes gentler.

The weather of the Stung Chinit River Basin is governed by the Southwest Monsoon which carries rain from May to October. Generally, the upstream Stung Chinit receives more rainfall of over 1,900 mm per year in the east. Also, the basin average annual rainfall and temperature are approximate 1,600 mm and 28 ºC, respectively (Table 1). The basic annual pattern of discharge shows an increase of discharge from late May and a sharp decrease around October and November although differences of annual patterns may exist between flood and drought years. Such fluctuations between dry and wet seasons will pose a great extent influences the utilization of water in the basin.

2.3 Data collection

The required data for this research consists of topography map, land-use and soil type maps, geospatial data, climatic and hydrological data. Besides, the 90 m resolution of digital elevation model (DEM) and 250 m resolution of soil types and land use maps used in the study were obtained from the Shuttle Radar Topography Mission (SRTM) and Mekong River Commission (MRC), respectively. The climatic data (rainfall and temperature) and related geospatial data are also received from MRC and Ministry of Water Resources and Meteorology. Likewise, the 50 km resolution of five RCMs, namely ACCESS, BCCR, CNRM, MPI, and REMO2009, under RCP4.5 and RCP8.5 were downloaded from the Centre for Climate Change Research (CCCR, 2020). A description of these employed RCMs can be also found on the website. All these data were checked before releasing to public users.

2.4 Hydrological model

The Soil and Water Assessment Tool (SWAT) model is a physically-based hydrologic model (Arnold et al., 1998). Core components in this model are hydrology, sedimentation/erosion, nutrients, plant growth, pesticides, stream routing, land management, and reservoir routing. It is a continuous simulation model which enables from daily to yearly time series data to be modeled. SWAT is also embedded in several software interfaces which allow discretizing a basin into sub-basins in accordance with the topographical information, and two crucial elements are also able to identify. The runoff generated from every sub-basin through the main river or channel can be computed by the hydrologic response units (HRUs), which are reckoned as lumped areas in the sub-basins which comprise of a distinctive soil, slope, and land cover in which the simulations can be conducted and formed at the sub-basin level, in respect to the land stage of the water cycle for the first element, whereas the last element is the river routing stage defined as the movement of water through the river network to the basin's outlet.

The hydrology at each HRU is examined by employing a water balance equation including rainfall, runoff, percolation, evapotranspiration, and return flow elements. The occurrence of rainfall can be either infiltrated or intercepted into the soil as a runoff in which some losses caused by evapotranspiration. Key hydrological processes in the SWAT model are an evapotranspiration, soil and root zone infiltration, soil and snow evaporation, baseflow and surface runoff as in the Eq. 1:

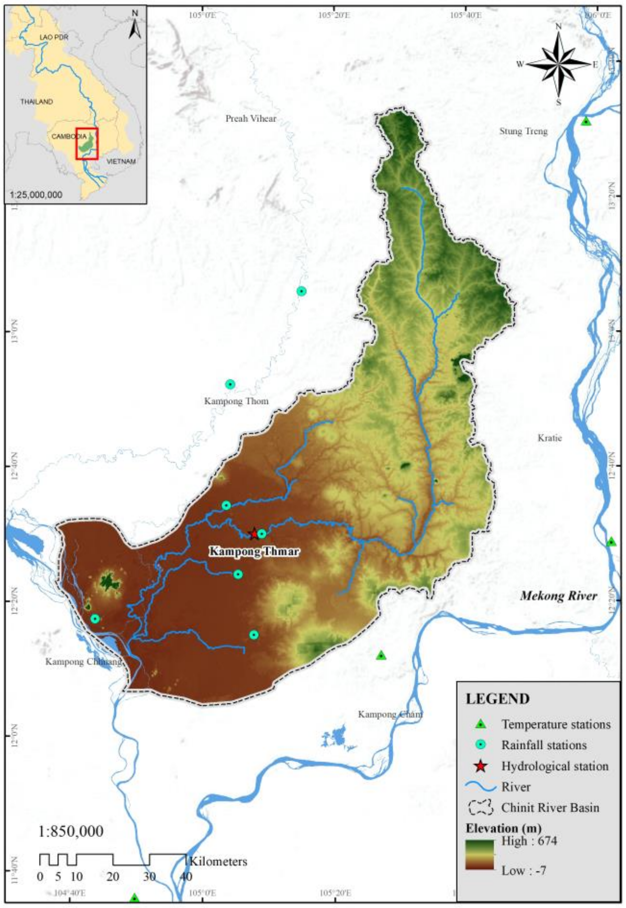

Fig. 2. Geographic map of the Stung Chinit basin

Table 1. Historical climatic and hydrological conditions of the Stung Chinit basin

Variable	Annual	Dry season	Wet season
Avg. temperature (°C)	28.2	28.1	28.4
Rainfall (mm)	1,582.0	260.9	1,321.1
River discharge (m^3/s)	22,280.8	5,122.1	17,158.7
Q5 (high flow) (m^3/s)	201.0	-	-
Q95 (low flow) (m^3/s)	4.2	-	-

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}\right) \qquad \text{(Eq. 1)}$$

Where:
SW_t = the soil water content (mm H_2O)
SW_0 = the initial soil water content on day 1 (mm H_2O)
t = the time (days)
R_{day} = the amount of precipitation on day i (mm H_2O)
Q_{surf} = the amount of surface runoff on day 1 (mm H_2O)
W_{seep} = the amount of water entering the vadose zone from the soil profile on day 1 (mm H_2O)
Q_{gw} = the amount of water return flow on day 1 (mm H_2O)

2.5 Bias correction method

The quantile mapping (QM) method is to correct the quantiles of RCM data to match the quantiles of observed data by creating a transfer function to shift the quantiles of precipitation and temperature. Distribution based QM (Gudmundsson et al., 2012; Teutschbein and Seibert, 2012), as well as the empirical QM (Gudmundsson et al., 2012) are used in correcting precipitation and temperature. However, the empirical QM was used with the 99-percentile table generated and linear interpolation between them in this study. The QM method was implemented in R language using package ‘qmap’ (Gudmundsson, 2014) with the following equations (Eq. 2 to Eq. 5):

$$P_{his}\left(d\right)^{*} = F^{-1}_{obs,\mathrm{m}}\left\{F_{his,m}\left(P_{his,m}\right)\right\} \qquad \text{(Eq. 2)}$$

$$P_{sim}\left(d\right)^{*} = F^{-1}_{obs,\mathrm{m}}\left\{F_{\mathrm{sim},m}\left(P_{\mathrm{sim},m}\right)\right\} \qquad \text{(Eq. 3)}$$

$$T_{his}\left(d\right)^{*} = F^{-1}_{obs,\mathrm{m}}\left\{F_{his,m}\left(T_{\mathrm{his},m}\right)\right\} \qquad \text{(Eq. 4)}$$

$$T_{sim}\left(d\right)^{*} = F^{-1}_{obs,\mathrm{m}}\left\{F_{\mathrm{sim},m}\left(T_{\mathrm{sim},m}\right)\right\} \qquad \text{(Eq. 5)}$$

Where:

F = the cumulative distribution function

F^{-1} = the inverse of the cumulative distribution function

3. RESULTS AND DISCUSSION

3.1 Hydrological model performance

Based on the sensitivity analysis and compiled similar research studies, twenty-two model parameters and its fitted values were used (Table 2). With these fitted values, the calibrated and validated SWAT model for the Stung Chinit basin at Kampong Thmar hydrological station was successfully conducted from 1997 to 2008. In Fig. 3, a comparison between simulated and observed river discharge at Kampong Thmar showed a close agreement between 1997 and 2008; however, the model can quite properly capture in the low flow, but not so good at estimating the peak flow. Also, most of the ordinates are slightly below and above the line 1:1, which demonstrate a rational model development. Although the model indicated overestimated flow, the overall model performance still demonstrated acceptable and reasonable. However, with this model result, the projected change in the high flow in the Stung Chinit river basin must be carefully analyzed.

Table 2. SWAT sensitive variables and their fitted values

Parameter name	Fitted value
1:R__CN2.mgt	0.304
2:V__ALPHA_BF.gw	0.765
3:V__GW_DELAY.gw	351.149
4:V__GWQMN.gw	888.657
5:V__GW_REVAP.gw	0.193
6:V__REVAPMN.gw	152.994
7:V__RCHRG_DP.gw	0.698
8:V__SURLAG.bsn	22.885
9:V__TRNSRCH.bsn	0.080
10:V__SLSUBBSN.hru	49.040
11:V__HRU_SLP.hru	0.493
12:V__OV_N.hru	10.243
13:V__LAT_TTIME.hru	138.277
14:V__ESCO.hru	0.547
15:V__EPCO.hru	0.329
16:V__CH_K2.rte	38.604
17:V__CH_N2.rte	0.114
18:V__ALPHA_BNK.rte	0.070
19:V__CANMX.hru	15.806
20:R__SOL_AWC(..).sol	0.039
21:R__SOL_ALB(..).sol	-0.205
22:R__SOL_K(..).sol	-0.141

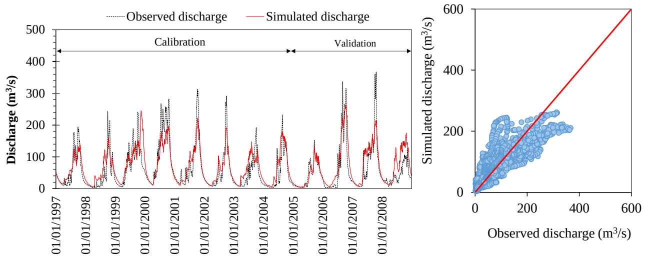

Fig. 3. Observed and simulated discharge at Kampong Thmar station between 1997 and 2008

Trang et al. (2017) and Khoi and Hang (2015) reported that the problem of underestimated flow may result from fewer and unwell-distributed rainfall stations within the study area and a curve number (CN2). Likewise, Shrestha et al. (2017) pointed out that these discrepancies might be characterized by rainfall data, potential errors in the observed flow data, and insufficient depiction of either man-made or natural processes in the model.

The SWAT model evaluated based on statistical indicators by Moriasi et al. (2007) indicated 0.74 and 0.71 of NSE, 0.75 and 0.76 of R^2, 0.51 and 0.54 of RSR, and -5.64 and -24.71 of PBIAS for the calibration (1997-2005) and validation (2006-2008) period, respectively. Some studies were also suggested that NSE and $R^2 > 0.6$ and PBIAS < 15% were indicated as decision guideline for hydrologic model studies. Although PBIAS in the validation period at Kampong Thmar indicated overestimated flow and as a satisfactory by Moriasi et al. (2007), the result from this model is reliable and acceptable enough to quantify the future change in flow regime in the Stung Chinit basin.

3.2 Future climatic and hydrological projection

Changes in future annual and seasonal climate from the individual and ensemble average bias-corrected RCMs under two emission scenarios (RCP4.5 and RCP8.5) with respect to the baseline climatic period (1985–2005) and future hydrology in comparison with the historical hydrological period (1997-2005) were quantified. Three future time horizons are the 2020s (2010–2039), 2050s (2040–2069), and 2080 (2070–2099). The following section consists of future temperature, future rainfall, future river discharge, and future hydrological extremes scenarios.

3.2.1 Future temperature scenarios

The annual and seasonal temperature will get warmer in three future time horizons according to individual and ensemble average RCMs under RCP4.5 and RCP8.5 in comparison with the baseline period (1980-2005) (Fig. 4). The basin average annual temperature is expected to increase between 0.2°C and 0.5°C in the 2020s, 0.5°C and 1.0°C in the 2050s, and 0.6°C and 1.8°C in the 2080s. Also, the highest increase in the average temperature of 1.8°C is expected to fall in the wet season (May-Oct) under RCP8.5 in the late 21st century. This is found to be higher than that of the dry season (Nov-Apr). Among employed RCMs, the ACCESS model is predicted to have a higher increase in the average temperature.

3.2.2 Future rainfall scenarios

The individual and ensemble average RCMs under two emission scenarios disagree in the direction of future rainfall in comparison with the baseline period (1985-2005) (Fig. 5). However, these fluctuated patterns of rainfall from these models are almost identical under the same future period and emission scenario. The annual and seasonal rainfall are expected to alter between -17% and 46% in the 2020s, -9% and 39% in the 2050s, and -21% and 101% in the 2080s. Noticeably, the higher relative change is expected to fall only during the dry season, particularly in the far future. A big gap and difference between one climate model to another climate model are also noticeable. Also, the annual and wet season rainfall remain fluctuating but mostly drop with less than 10%. However, the dry season rainfall is projected to increase from most of these RCMs. This might partly result from the bias correction method which did not perfectly reduce the wetness in the dry season (Nov-Apr).

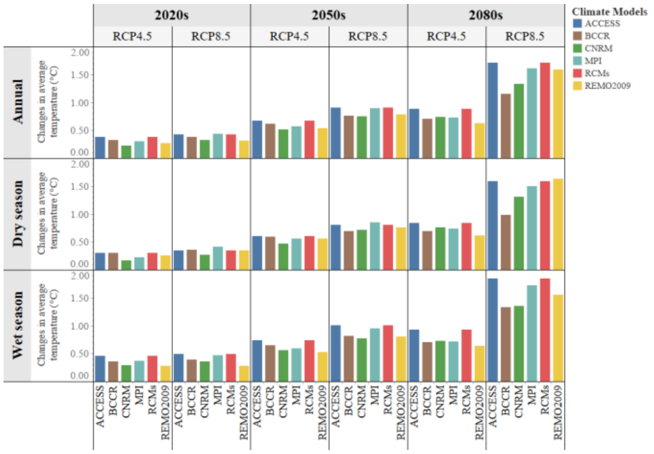

Fig. 4. Changes in annual and seasonal average temperature in the 2020s, 2050s, and 2080s in the Stung Chinit basin

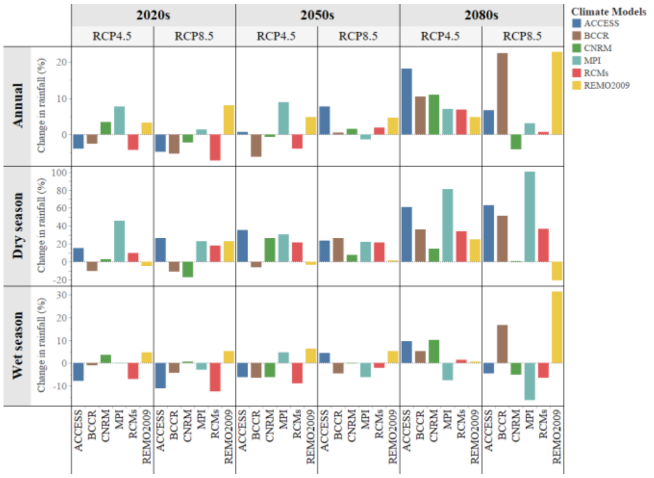

Fig. 5. Changes in annual and seasonal rainfall in the 2020s, 2050s, and 2080s in the Stung Chinit basin

3.2.3 Future river discharge scenarios

Based on individual and ensemble average RCMs under RCP4.5 and RCP8.5, the average annual and seasonal river discharge at Kampong Thmar are projected to increase between 8% and 144% although there will be 10% reduction in the annual and wet season rainfall (Fig. 6). The highest increase is expected to occur during the dry season in the late 21st century. Also, the annual and wet river discharge is projected to rise between 8% and 59%, 13% and 65%, and 14% and 120% in the 2020s, 2050s, and 2080s, respectively. In the dry season, the increase in river discharge will be between 49% and 100% in the 2020s, 51% and 99% in the 2050s, and 44% and 144% in the 2080s.

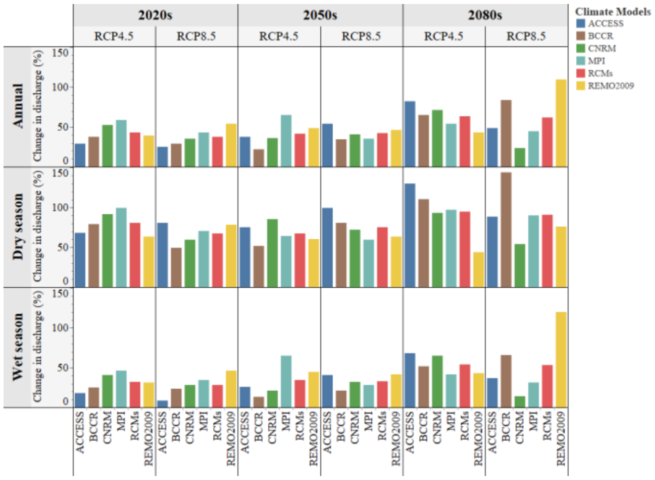

Fig. 6. Changes in river discharge at Kampong Thmar in the 2020s, 2050s, and 2080s in the Stung Chinit basin

3.2.4 Future hydrological extremes scenarios

Two indicators, namely Q5 (high flow) and Q95 (low flow) are commonly used to quantify the chance of future flood and drought occurrences resulting from effects of both human system and natural systems like climate change, etc. (Fig. 7). The Q5 and Q95 were obtained from flow duration curves as depicted in Fig. 8. Regarding individual and ensemble average RCMs under RCP4.5 and RCP8.5, the Q5 and Q95 at Kampong Thmar are expected to rise in the future. The Q5 is projected to increase between 10% and 37% in the 2020s, 20% and 51% in the 2050s, and 12% and 85% in the 2080s. The Q95 is also expected to rise from 73% to 139%, 42% to 156%, and 58% to 254% in the 2020s, 2050s, and 2080s, respectively. Likewise, the relative change of these indicators from the ensemble average RCMs under two emission scenarios will be fall within the mentioned range. Increasing in the Q95 is expected to be greater than that of the Q95. This also suggested that drought will be plausibly less occur while the flood may be quite more frequent in comparison with past events.

3.3 Discussion

In previous studies, Sreymom et al. (2015) found that the average temperature in the Stung Chinit basin will get warmer in the future. The wet and dry season rainfall will mostly increase and decrease from ECGAM4 model under SRES A2 and SRES B2, respectively. However, the annual and seasonal flow is expected to increase between 12% and 39% except for the dry season flow (-9%) under SRES B2 in the 2050s. Sreymom et al. (2015) also suggested that a greater risk of flash flooding and severe drought might occur.

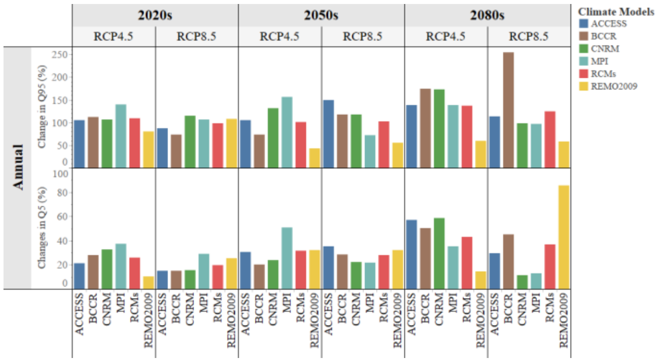

Fig. 7. Changes in Q95 and Q5 at Kampong Thmar in the 2020s, 2050s, and 2080s in the Stung Chinit basin

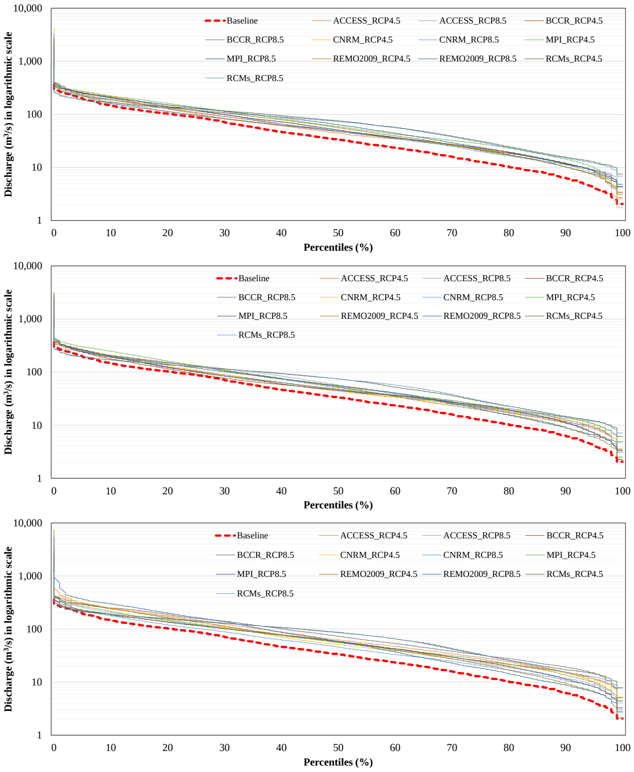

Fig. 8. Flow duration curve at Kampong Thmar in the 2020s, 2050s, and 2080s in the Stung Chinit basin

However, according to Heng et al. (2017), the annual and seasonal flow from ECHAM4 under SRES A2 tend to reduce between 14% and 45% by 2050. Also, the dry season flow will be more severe from decade to decade whereas the wet season flow can be lower. Likewise, Suong and Sith (2019) suggested considering the risk level of ecosystems in the Stung Chinit river although three GCMs disagree in future discharge projection. The future discharge at Kampong Thmar in the Stung Chinit basin from three GCMs under RCP6.0 is also projected to drop from 26% to 46% in the 2030s, from 27% to 50% in the 2060s, and from 25% to

56% in the 2090s (Oeurng et al., 2019). Also, the Q5 is expected to be lower reduction than the Q95. This demonstrated that the basin will plausibly experience extreme drought rather than a flood, which has a similar projection result in the mid and far future based on the study of drought projection in the Indochina region by Chhin et al. (2020). However, Try et al. (2020) found out that the Lower Mekong Basin will face the severe flood magnitude by far future resulting from the increase of rainfall between 6.6% and 14.2% under MRI-AGCM3.2H and MRI-AGCM3.2S models. Noticeably, Chhin et al. (2020) and Try et al. (2020) used global or regional datasets (e.g. APHRODITE) as observed climate variables (e.g. rainfall), so uncertainties still existed in the result. Also, changes in annual climate in the Stung Chinit basin by Oeurng et al. (2019) were also excluded making it so doubtful about its future direction.

Although unclear alterations in the projected rainfall from different RCMs in this study were assessed, flow regime at Kampong Thmar is still predicted to increase in the future. So, different future climatic and hydrological projections may result from the uses of (1) historical data with a number of stations (either observed or global reanalysis data), (2) characteristics of climate models (global or regional, the resolution with dynamic or statistic downscaling, year, emission scenarios, etc.), (3) bias correction methods, (4) hydrological models used and developed, and (5) other unknown variables of the system (e.g. land-use change, water infrastructure development, etc.). However, these uncertainties can be interpreted by introducing multiple climate models (Deser et al., 2012), emission scenarios, downscaling methods (Li and Jin, 2017), and hydrological models (Lee and Bae, 2018). These uncertainties are still reckoned as uncertainties of any kind of future projection studies (Lu et al., 2019), but somehow the analysis can assist in visualizing the future climate and hydrology in any basin (Chen et al., 2011).

4. CONCLUSIONS

Based on these results, several conclusions can be made as:

- the average temperature is projected to get warmer in the future. The highest increase of 1.8°C average temperature is expected in the 2080s under RCP8.5.
- the future rainfall indicated an unclear direction, but the projection in annual and seasonal flow regime at Kampong Thmar in the Stung Chinit basin is expected to likely increase, particularly in the dry season.
- the Q5 and Q95 alterations will rise from all RCMs in three future time horizons. This means drought will be likely less occur while flood will be more frequent.

Some recommendations can be listed as the following:

- planning, managing, and improving water security and climate change through physical infrastructure and technology interventions
- strengthening catchment development and mainstreaming climate resilience into local and community's development planning
- future research development on flood and drought, land-use change, reservoir system operation, etc.

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