Quantification and allocation of uncertainties of climate change impacts on hydropower potential under 1.5°C and 2.0°C Global Warming Levels in the Benue River Basin, Cameroon

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Outline

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1) Background

- Climate change is now a major concern around the World and there is a clear agreement that temperature increases will affect different mechanisms of the climate system.

- Since the middle of the 1990s, discussions about setting targets to limit global warming by a predefined threshold have been actively pursued (WBGU 1995).

- In 2015, the Paris Agreement (COP21) was adopted with the main goal to pursue efforts to limit the global-mean temperature at 1.5°C and well below 2°C above pre-industrial levels, which would significantly decrease the risks and impacts of climate change (Schleussner et al., 2016).

- To achieve the Paris Accord, renewable energy sources are being promoted which are clean and increasingly competitive energy sources.

- Hydropower is the world's largest producer of renewable energy and represents more than 43% of the low-carbon energy. But it is extremely sensitive to climate variability and change (IHA, 2022).

- Therefore, it is of paramount importance to understand the effects of climate change and variability on hydropower generation.

- Several studies have been conducted around the World to evaluate the potential impacts of climate change on hydropower generation (Falchetta et al., 2019; Obahoundje and Diedhiou 2022; Wasti et al., 2022).

- However, the impact of climate projections on river discharge and hydroelectricity is associated with large uncertainties. These arise from the different steps of the modeling chain which include emission scenarios, global climate models (GCMs), downscaling techniques (dynamical or statistical), hydrological models' structure and parameter uncertainty (Hattermann et al., 2018).

- For better water management and for science-based decision making, the quantification of uncertainty sources in climate-impact studies is of great importance.

- In the last decade, numerous previous studies have been focused on climate change impacts on hydrology and their sensitivity to the different sources of uncertainty (Hattermann et al., 2018; Ohn et al., 2020; Lemaitre-Basset et al., 2021; Gaur et al., 2021).

- Few studies address the impacts of relatively low magnitudes of global warming - this is of great importance because seemingly small differences in temperature will have a strong impact in specific regions and ecosystems (Hattermann et al., 2018).

2) Objectives

(i) to assess the consequences of climate change on hydro-climatic components and hydropower generation in the Headwaters of the Benue River Basin (HBRB) under GWLs of 1.5°C and 2.0°C above preindustrial levels;

(ii) to quantify the total uncertainty in both projected hydroclimatic parameters and Hydropower

(iii) to quantify individual or combined uncertainties that come from different sources in the modeling chain (see Fig. 1)

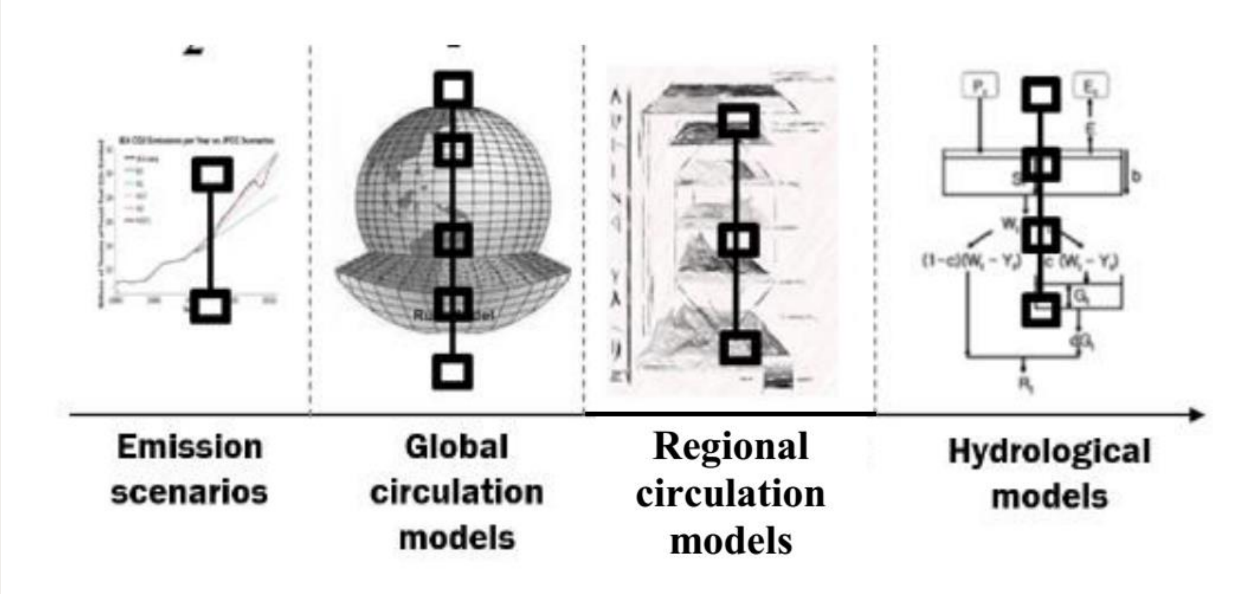
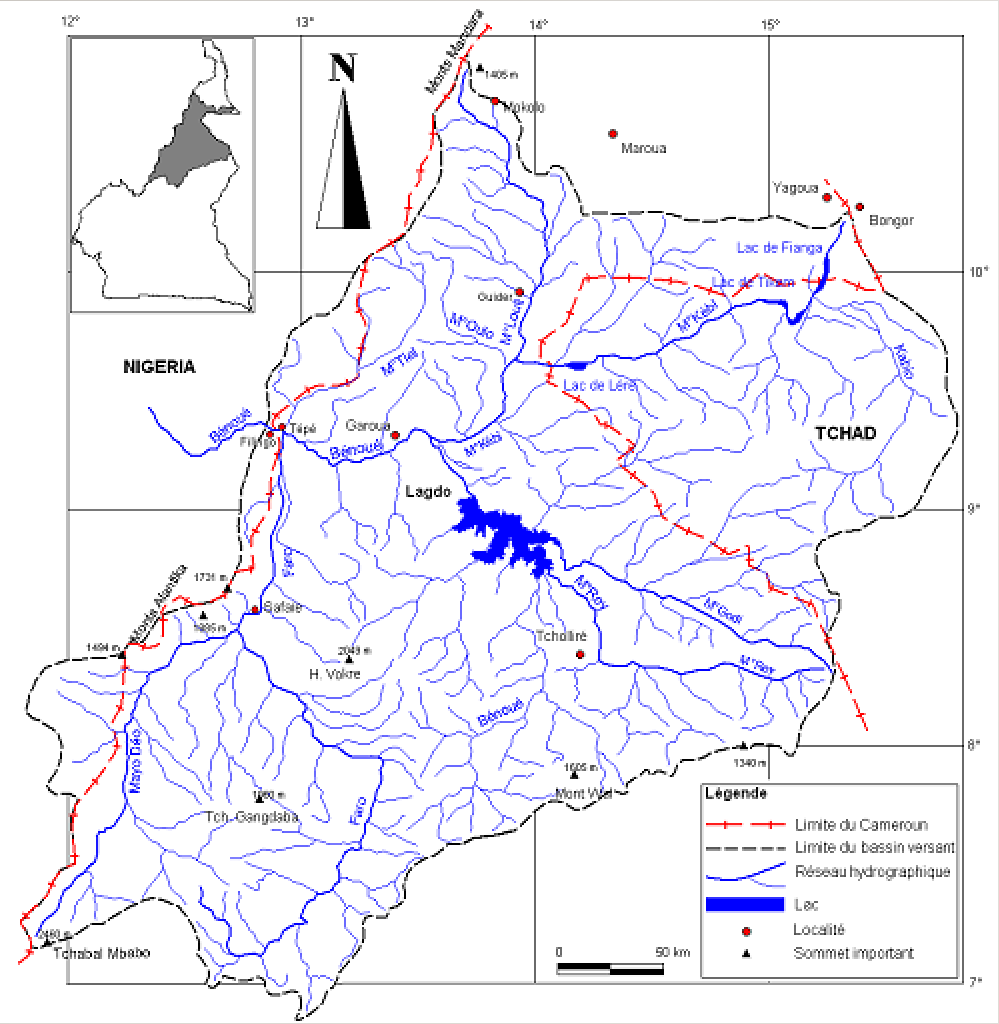
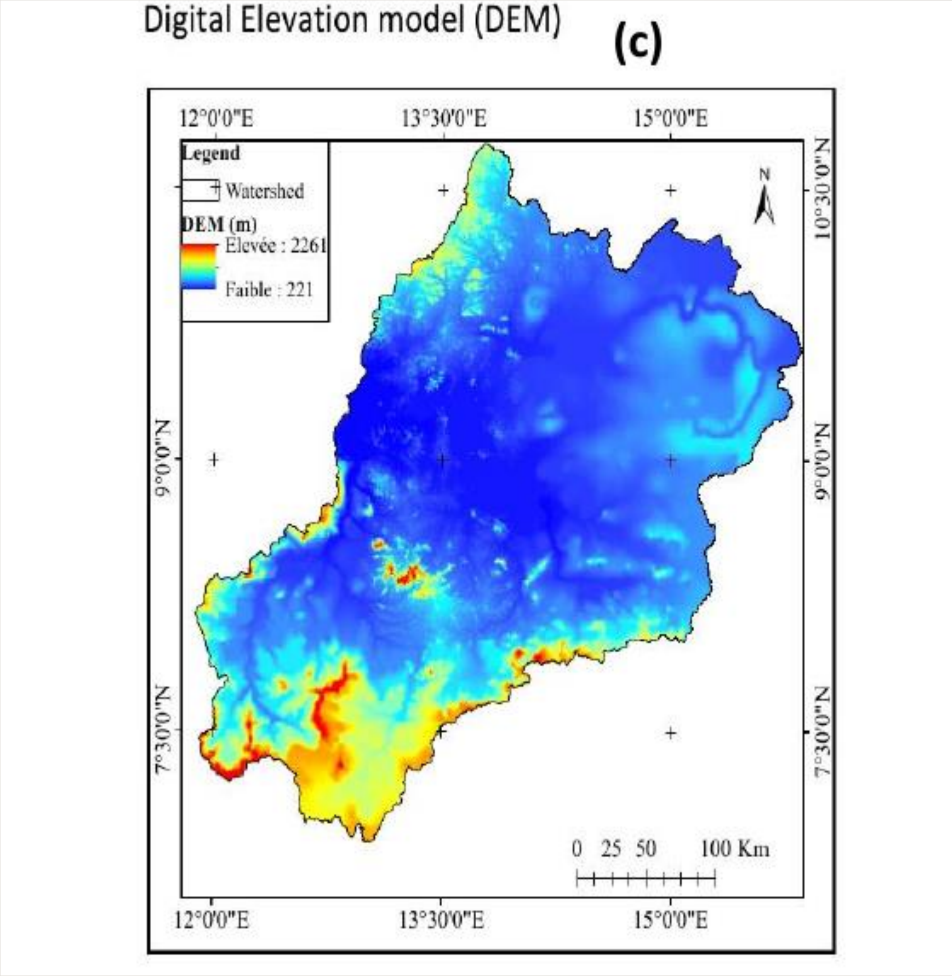


Fig. 1. Impact modeling chain for hydrological projections used in this study

3) Study area and data





Climate: Sudan-Sahelian

Rainfall: 900 and 1500 mm

Temperature: 28°C

Fig. 2: Study area

Observed hydrometeorological data

- daily meteorological data (DNM)
- Daily measured streamflow data (SIEREM) database, http://hydrosciences.fr/sierem)

Climate models data

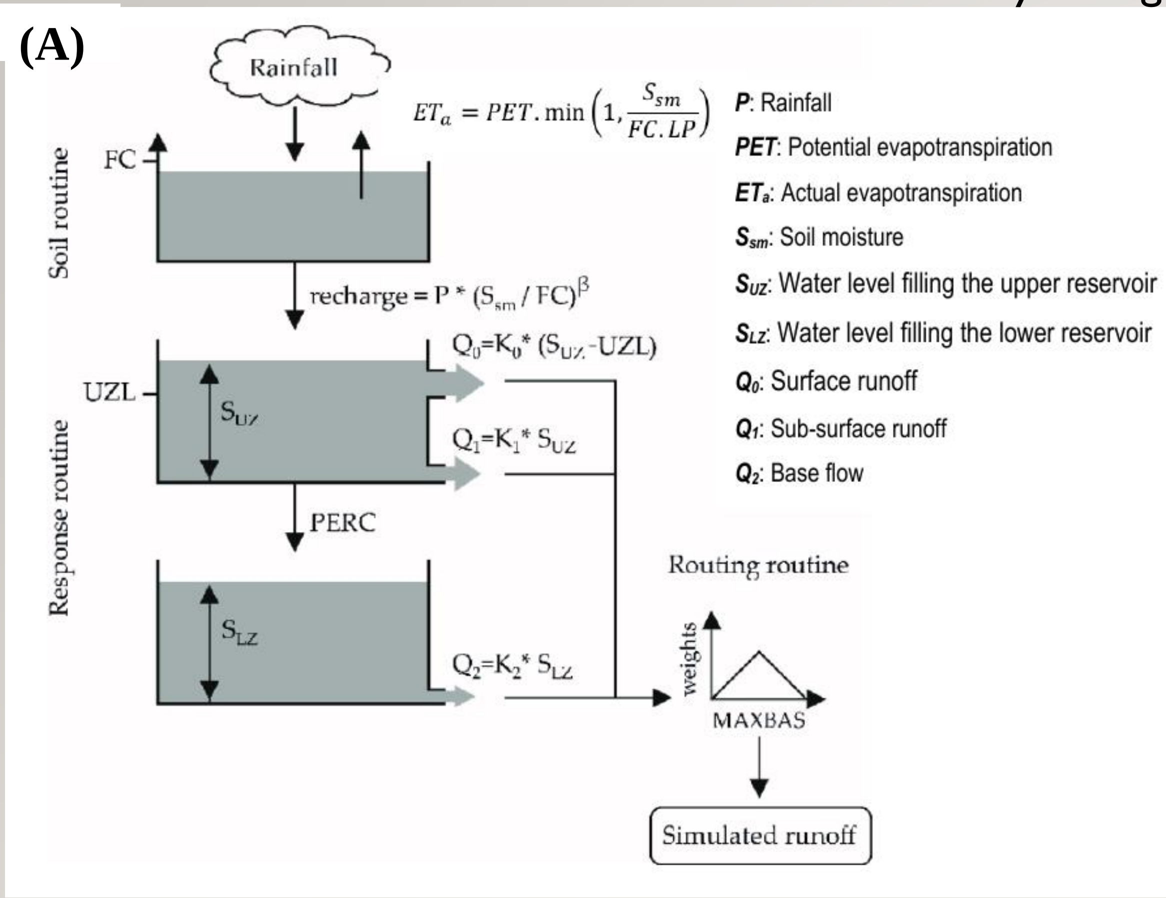
Precipitation and mean air temperature were obtained from 17 CORDEX-Africa climate simulations under two representative concentration pathways, RCPs 4.5 and 8.5, to a resolution of 0.44 degrees.

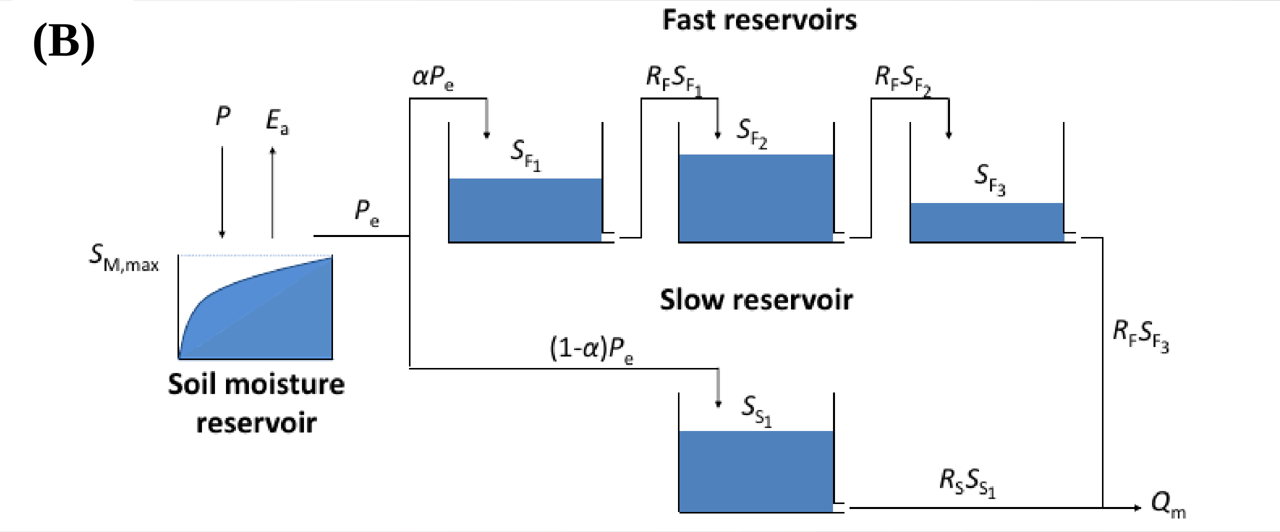
To define the Global Warming Levels (GWLs), we used the method described in Nikulin et al. (2018).

Several studies have analyzed the performance of these data (e.g: Fotso-Nguemo et al., 2016; Vondou and Haensler, 2017; Fotso-Nguemo et al., 2017; Pokam et al., 2018; Tamoffo et al., 2019b; Fotso-Nguemo et al., 2019; Nonki et al., 2019; Taguela et al., 2020; Fotso-Kamga et al., 2020; Fotso-Nguemo et al., 2022 among others)

4) Materials and Methods

Hydrological models





The model calibration and uncertainty analysis were conducted using the GLUE method [Biven and Binley 1982] and Kling–Gupta efficiency (KGE; Gupta et al., 2009) as objective function .

*Fig. 3. Schematic representation of the different hydrological processes in the two hydrological models: (A) HBV-Light model (***Seibert 2005)***and (B) HYMOD* **(Gharari et al. 2013)**

4) Materials and Methods

Hydropower potential estimation

- ✓ The hydropower potential is the total energy from all natural runoff at stream gradient over the entire domain. It is achieved by converting the potential and kinetic energy of the water into electrical energy by electro-mechanical means (Turbines and Generators).

$$N_p = Q \times H \times \rho_w \times g \times \eta \qquad (1)$$

where N_p is the gross hydropower potential (W), Q is the streamflow (m^3/s), H is the hydraulic head (m), ρ_w is the water density (kg/m^3), g is the gravitational acceleration (m/s^2) and η is the total plant efficiency (%).

- ✓ Historical and future stream flows simulated by the two calibrated hydrological models were used to estimate both historical and future hydropower potential through Eq. (1).

- ✓ The climate change signal was compute using Eq. 2, while the avoided impacts (AI) caused by additional 0.5°C warming is computed using Eq. (3):

$$CCS(\%) = \frac{(X_{future} - X_{present})}{X_{present}} \times 100 \qquad (2)$$

$$AI = \left[\frac{GWL_{2.0} - GWL_{1.5}}{GWL_{2.0}}\right] \times 100 \qquad (3)$$

4) Materials and Methods

Uncertainty quantification and decomposition

- ✓ We use a sensitivity test based on the ANalysis Of VAriance (ANOVA; Sawyer, 2009) to allocate and quantify the main sources of uncertainty in the hydrological impact modeling chain. It is a statistical test for detecting differences in group means when there is one parametric dependent variable and one or more independent variables.

- ✓ In ANOVA, the total sum of squares (SST, Eq. (4)) is used to express the total variation that can be attributed to the various groups:

$$SST = \sum_{i=1}^{N_{RCP}} \sum_{j=1}^{N_{GCM}} \sum_{k=1}^{N_{RCM}} \sum_{l=1}^{N_{HM}} \left(X_{ijkl} - \overline{X}\right)^2 \qquad (4)$$

where X_{ijkl} is the value of hydro-climate variable X corresponding to RCP i, GCM j, RCM k and HM l respectively and $\overline{X}$ is the overall mean.

- ✓ SST can be further divided into four main effects (SS_{RCP}, SS_{GCM}, SS_{RCM} and SS_{HM})and into Residuals variance ($SS_{Residuals}$):

$$SST = SS_{RCP} + SS_{GCM} + SS_{RCM} + SS_{HM} + SS_{Residuals} \qquad (5)$$

- ✓ Then for each uncertainty source Y, its contribution (η_Y^2) to the overall uncertainty of X is calculated as follows:

$$\eta_Y^2 = \frac{SS_Y}{SST} \qquad (6)$$

5) Results

Hydrological models evaluation results

(A)

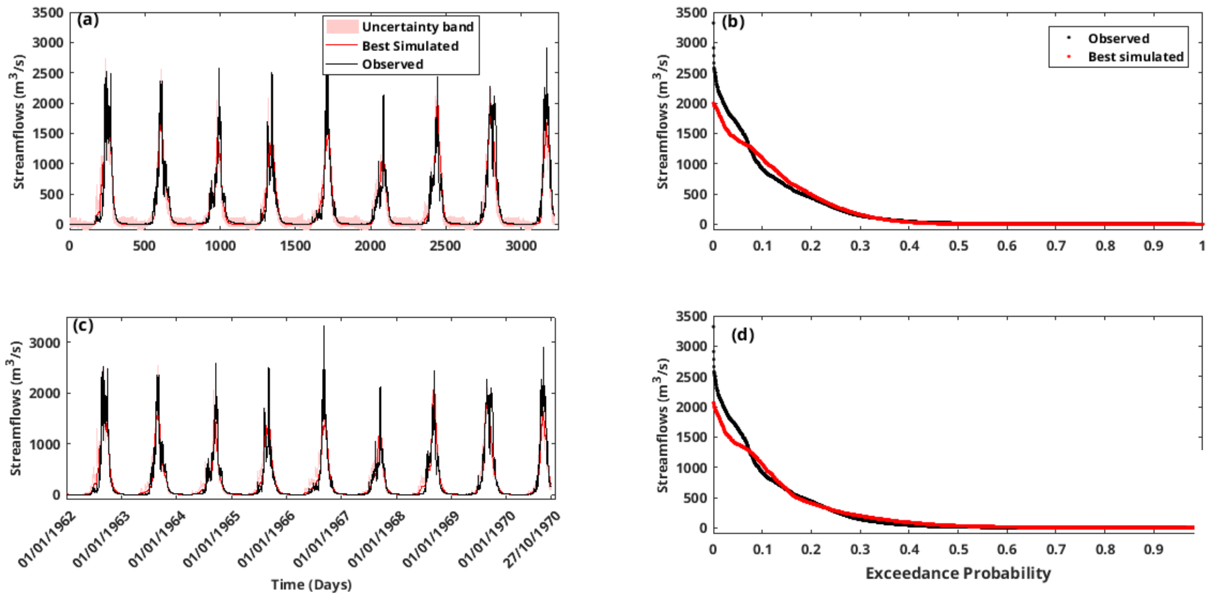
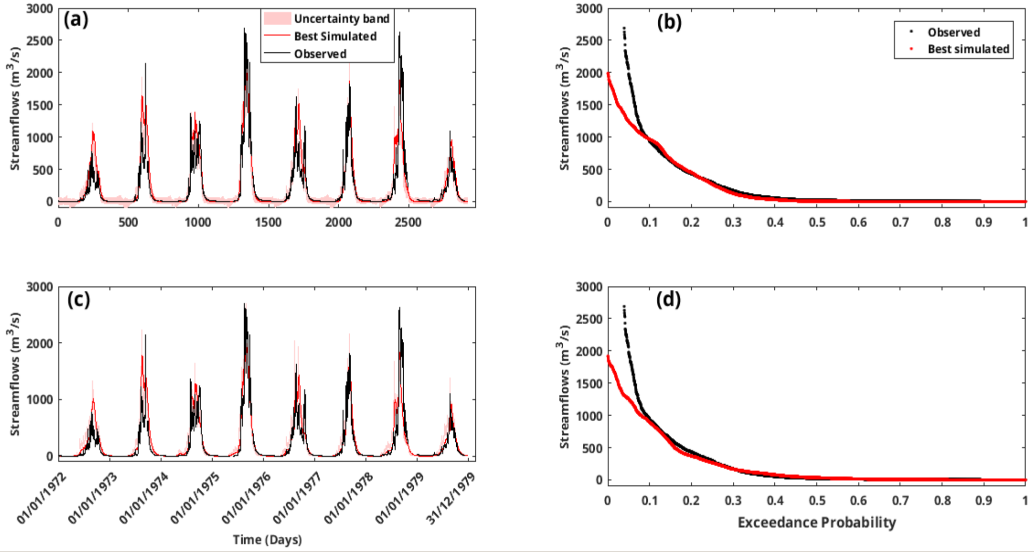


Fig. 4: Comparison between observed and simulated streamflows in the HBRB. (A) Calibration; (B) Validation

(B)



Models		KGE	NSE	RSR	PBIAS (%)	R^2	P-factor	R-factor
HBV-Light	Calibration	0.88	0.86	0.38	-1.96	0.93	0.83	1.49
	Validation	0.83	0.78	0.48	18.06	0.90	0.78	1.30
HYMOD	Calibration	0.85	0.84	0.40	-2.31	0.92	0.41	-0.14
	Validation	0.83	0.76	0.49	16.8	0.88	0.43	-0.16

5) Results

Projected change in precipitation and PET under different GWLs

(A)

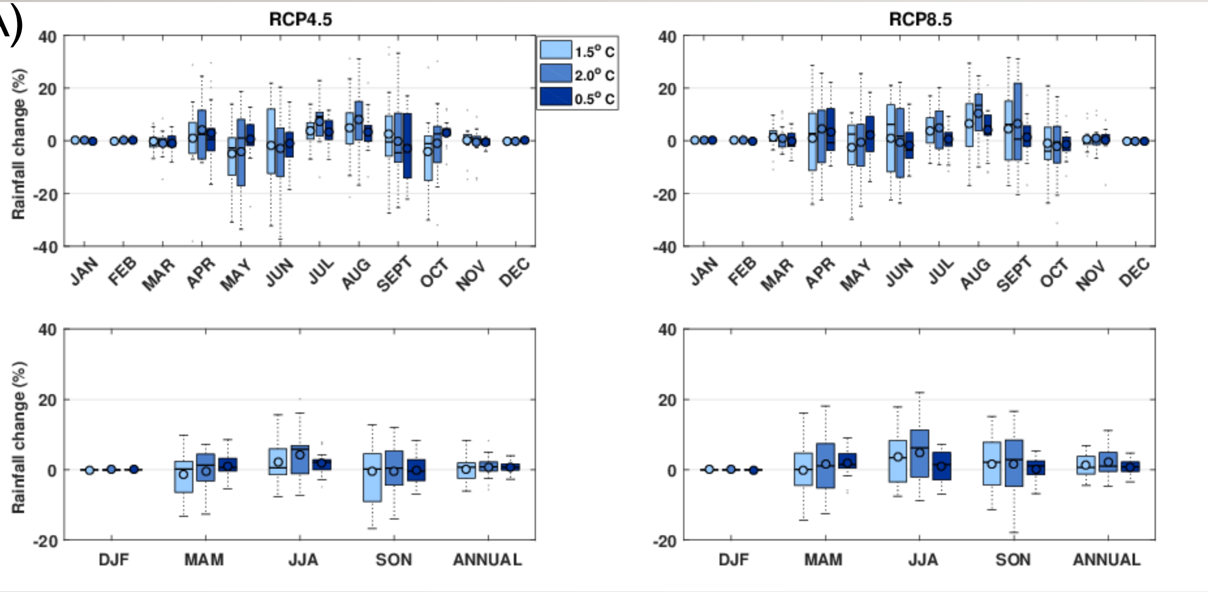
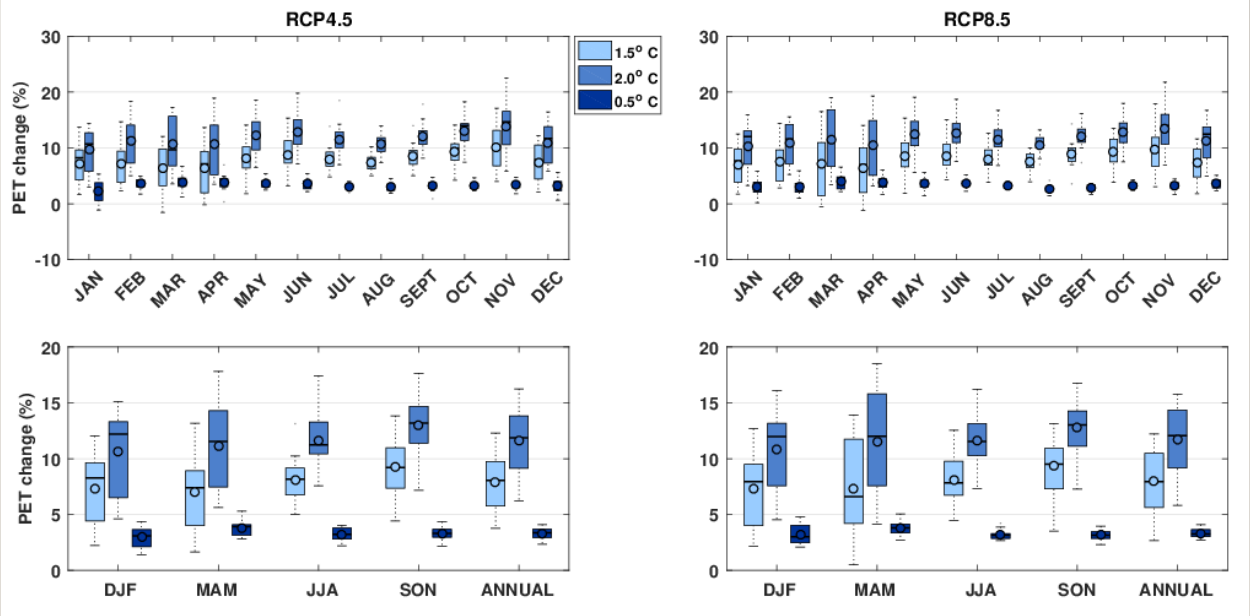


Fig. 5. Projected change in monthly, seasonal and annual Rainfall (A)and PET (B) at 1.5°C and 2.0°C GWLs as well as change associated with the additional 0.5°C warming.

(B)



5) Results

Projected change in water recharge and Hydropower potential under different GWLs

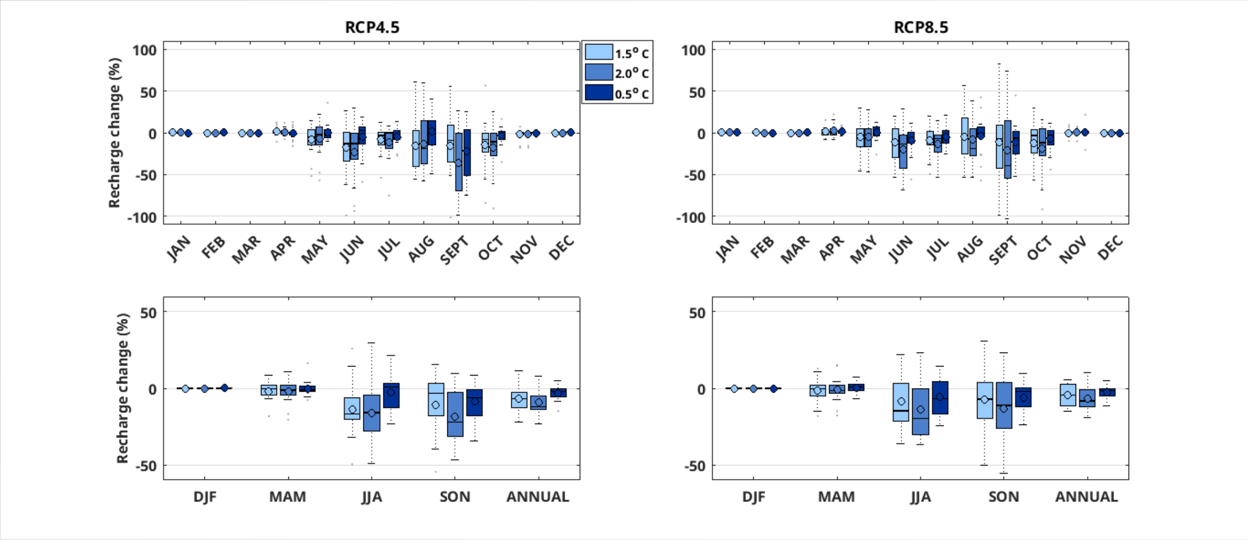
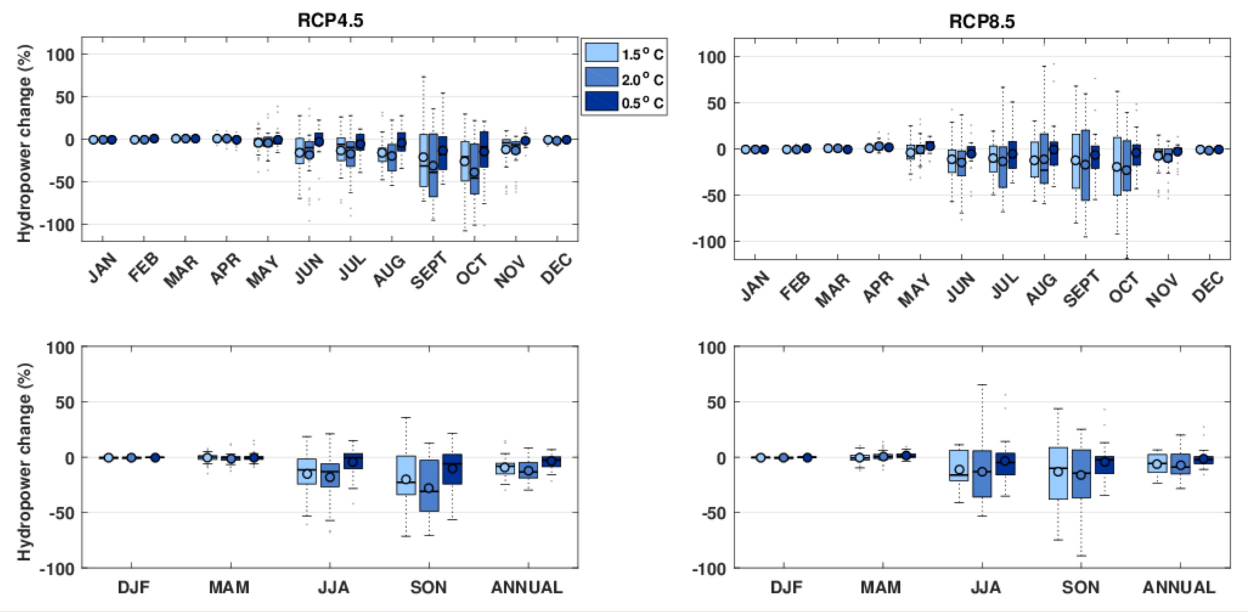


Fig. 6. Projected change in monthly, seasonal and annual water recharge (A)and Hydropower potential (B) at 1.5°C and 2.0°C GWLs as well as change associated with the additional 0.5°C warming.



5) Results

Uncertainty estimation and decomposition for hydropower potential projections

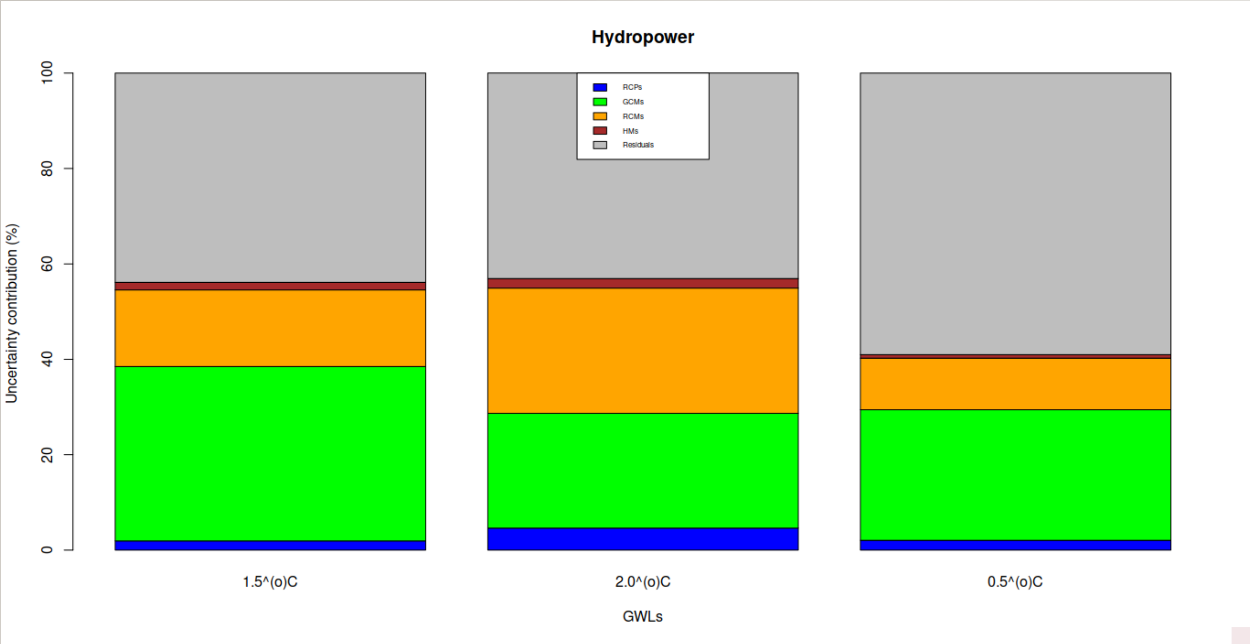


Fig. 7. Contribution of different sources to uncertainty in annual hydropower potential projections under different GWLs.

Table 4: Results of significance statistical test (F-test) (*test significant at the 95% confidence level ($\rho < 0.05$; **test significant at the 99% confidence level ($\rho < 0.01$); ***test significant at the 99.9% confidence level ($\rho < 0.001$))

	1.5°C GWL		2.0°C GWL		Additional 0.5°C warming	
Effects	F-score	P-value	F-score	P-value	F-score	P-value
RCPs	2.34	0.1322	5.67	0.0209*	1.84	0.1811
GCMs	5.52	0.000044***	3.70	0.0017**	3.07	0.0064**
RCMs	4.85	0.00208**	8.07	0.000037***	2.43	0.0591.
HMs	1.92	0.1719	2.45	0.1238	0.66	0.4208

6) Conclusions

- The hydrological models perform well, and that their application for supporting water resources management strategies within this basin is possible.

- Despite uncertainties, annual rainfall is projected to slightly increase while temperature and PET are projected to increase under both GWLs and RCPs scenario. This change is projected to increase/decrease with the increasing GWLS.

- The increase in PET and change in rainfall will significantly impact the water availability and quantity in the HBRB which negatively affects the water recharge, streamflow and hydropower potential of the Lagdo dam.

- Climate models (both GCMs and RCMs) are the dominant and significant sources of uncertainty in the impact modeling chain for hydropower projections under both GWLs. At the 2.0°C GWL, uncertainty is largely dominated by RCMs, whereas in 1.5°C GWL, contribution of GCMs is greater.

- The additional warming of 0.5°C will change the hydrological cycle and water availability in the HBRB, with potential to cause challenges to water resource management, hydro-power productionGCMs are found to be the largest and significant contributor of uncertainty in the modeling chain.

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Abstract

Hydropower is the world's largest producer of renewable energy and represents more

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Thank you for kind attention