Climate change impacts on hydro-generation and land suitability for agriculture in Cambodia, Laos and Myanmar

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Abstract – *This paper quantifies and analyses the impacts of climate change on water availability for hydro generation and land suitability for key crops in three least developed countries in the Greater Mekong Sub-region, namely, Cambodia, Laos and Myanmar. The method used for the climate study is supported by the inter-sectoral model inter-comparison project (ISIMIP database). The recent ISIMIP input dataset, ISIMIP2b, outlines simulation scenarios divided into different emissions pathways (or "Representative Concentration Pathways" known as RCPs). This paper focuses on the two extreme RCPs, specifically RCP2.6 and RCP8.5, which would result in global average temperature increases of approximately 1.6 and 4.3°C respectively. Th analysis concentrates on the difference between the historic period and the end of the century (toward 2100) for the climate conditions for the future. The fuzzy logic global land suitability model has been used to calculate the suitability of the land to support growing crops as well as to investigate how the climate changing could impact this. The analysis shows that quite significant changes in hydro-generation potential can occur depending on the region: Laos and Cambodia show decrease when Myanmar shows increase in output potential between present and RCP2.5 and RCP8.5 respectively. Quite significant increases or decreases in land suitability can occur depending on the region and the crop.*

Keywords – Climate Change impacts, land Suitability, hydro generation, agriculture

1. INTRODUCTION

The economy of the Greater Mekong sub-region heavily depends on a hydro-based electricity system and agricultural output. These sectors are particularly important for the development of the least-developed countries in this region, namely Cambodia, Laos and Myanmar (also referenced as KHM, LAO, MNR afterward) (Vicol et al 2017 and FAO 2020; Grumbine et al 2012, ADB 2018 and ADB 2019). Hydro and other renewables such as biomass, wind and solar are expected to play a crucial role in improving electricity access and reducing greenhouse gas emissions in the case study countries. Hydropower and agriculture are also vulnerable to climate impacts themselves. Rising temperatures, changing precipitation patterns, increasing weather variability and extreme events are projected to affect the energy system extensively (Cronin et al 2018). Monthly variation in precipitation under climate change will affect the water availability (inflow) for hydro power generations and agriculture and the land suitability for various crops due to water scarcity and temperature change. Unfortunately, weather extremes driven by climate change can be particularly detrimental for hydro based electricity systems (Carvajal et al., 2019) and agriculture (Conway and Shipper, 2011) in developing countries. Developing countries are more at risk from severe and long-lasting climate change impacts as their citizens are susceptible to poverty-environment traps that further increase their vulnerability to these impacts (Barbier and Hochard 2020).

The main objective of this paper is to understand the climate induced changes in precipitation, water inflow, and land-suitability for agriculture and hydro generation in the case study countries where electricity system is heavily dependent on hydro and the economy of the rural population heavily depends on the agriculture. Rural agrarian communities are highly vulnerable to climate change as their income heavily depends on agriculture and has very limited access to electricity (Morton 2007). Access to electricity and climate resilience in the agriculture sector are expected to facilitate enhanced economic activities, secure jobs, and income generated by the sector and its supply chain for rural communities. Further, increased development, driven by access to clean energy and employment, is also key to achieve several Sustainable Development Goals (SDGs) such as health and wellbeing, education, poverty alleviation, reducing inequality and promoting gender equality.

We use different databases (CMIP5 for climate and ISIMIP for hydropower data) as well as a modelling tool (land suitability model) to conduct these analyses. The paper is divided into 5 sections. After the introduction, Section 2 describes the climate and projected climate change impacts on temperature and precipitation in the three case study countries. Section 3 presents and discusses the climate change impacts on hydropower under different scenarios, for which we use publicly available data from Global Circulation model (GCM) and Global Hydrological Models (GHM) from the ISIMIP project (The Inter-Sectoral Impact Model Inter-comparison Project). Section 4 analyses the impacts on land suitability for certain key crops for which the results were generated at UCL using a Fuzzy Logic Land

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Suitability Model (Zabel et al. 2014, Cronin et al. 2020). Section 5 concludes the study.

2. CLIMATE

The countries of Myanmar, Laos and Cambodia lie in the tropical zone north of the Equator in South East Asia. The region straddles a wide range of latitudes (10 to 25° north of the equator) and therefore experiences a range of climates. The Southern part (Cambodia) sits close to the equator, experiencing a tropical climate, whilst the Northern regions of Myanmar and Northern Laos reach into a cooler highland subtropical climate, where there is greater seasonal variation and heavy snow fall over the mountain ranges (altitude up to 5,000m).

2.1 Method

The method used for the climate study is supported by the inter-sectoral model inter-comparison project. We used the ISIMIP database to calculate the changes in surface temperature and precipitation for the three countries. As part of ISIMIP, a bias-corrected climate forcing data set based on CMIP5 was produced (Hempel et al. 2013). The input dataset, ISIMIP2b, outlines simulation scenarios divided into different emissions pathways (or "Representative Concentration Pathways" known as RCPs). Four pathways were constructed for the IPCC fifth Assessment Report (AR5) in 2014. The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases emitted in the future. The RCPs, originally RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after the radiative forcing values in the year 2100 that would result from the given pathway of GHG emissions. They would result in different global temperature changes relative to pre-industrial levels: 1.6, 2.1, 2.6, 4.3°C respectively, as described in Stocker et al. 2013.

This paper focus on the two extreme RCPs, RCP2.6 and RCP8.5, which would result in global average temperature increases of approximately 1.6 and 4.3°C respectively. It concentrates on the difference between the historic period and the end of the century (toward 2100) for the climate conditions for the future. The general attributes of the ISIMIP2b input data used in the report are as follows:

- Experiments: historical, RCP2.6 to RCP8.5
- Four GCMs: GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC5 (see table 1)
- Periods: 6 hourly data point from 1970 to 2100
- Spatial resolution: 0.5 x 0.5 degrees

Table 1. GCMs included in the ISIMIP database and their respective institutions.

GCM	Institution
GFDL-ESM2M	National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA
HagGEM2-ES	Met Office Hadley Centre, Fitzroy Road, Exeter, Devon, EX1 3PB, UK
IPSL-CM5A-LR	Institut Pierre Simon Laplace, Paris 75252, France
MIROC5	Meteorological Research Institute, Tsukuba, Ibaraki 305-0052, Japan

The data are extracted for 30-year periods, as usual for climate change analysis, for the historic period (1970-2000) and the end of century (2070-2100) for RCP2.6 and RCP8.5. The data for the end of the century is derived from the four Global Circulation Models (GCMs), GFDL, HadGEM2, IPSL, and MIROC (Table 1) as they represent a wide range of the global mean temperature and precipitation changes seen in the full CMIP5 model ensemble (Warszawski et al. 2014).

2.2 Climate change in the region

Climate change affects the mean climatic conditions and, more importantly, the variability around the mean and the occurrence of extreme weather events. It is widely acknowledged that temperature changes will not directly cause the majority of climate impacts. Changes in precipitation, weather variability, and extreme weather events are of more consequence – especially global monsoon changes, as well as drought or flood events. The last IPCC projections indicate substantial increases in the frequency of hot days and nights over South East Asia and increases in annual national precipitation. Precipitation projections are more uncertain than temperature and considerable regional variations exist. Projections of mean annual rainfall from different models in the IPCC ensemble (including all the represented GCMs in the CMIP5 database) are broadly consistent in indicating increases in rainfall for Cambodia and Laos (IPCC AR5). This increase is mainly due to the projected increases in wet season rainfalls (up to +40% by the 2090s) but is partially offset by projected decreases in other seasons. It has been remarked that these increases during the wet season arise mainly due to increases in heavy events rainfall.

Figure 1 presents the monthly mean temperature (and change) for the 3 climates from the ISIMIP results, compiled for this study. The temperature response to climate change over the 3 countries an increase of 1.5 to 2 °C for the RCP2.6 and around 4°C for RCP8.5 with highest increase for Laos in the 2 different scenarios. Geographically the differences are higher for the higher elevation regions over Laos and Myanmar as seen in Appendix 1 and 2 for the 2 RCPs at the start of the wet season (May for Laos and June for Myanmar).

The message from the climate data is more uncertain concerning the precipitation levels under climate change. Out of the 4 climate models used (GCMs), one is showing a weaker annual increase than the three other in its response to emissions of greenhouse gases. However, the clear message is that, unlike for temperature, the response of precipitation to climate change is seasonal. In figure 2 the monthly precipitation levels show a strong decrease at the start of the rainy season and an even stronger increase (in absolute terms) during the rainy season. On a national level, the conclusion is a delay in the start month of the rainy season (April and May) with stronger events during this shorter season increasing the amount of rain over some months (from July to December). On a geographical distribution in Appendix 3 and 4 the decrease in the start of the rainy season is especially strong over the lowland of

Myanmar, as well as Laos and Cambodia (as shown in blue negative values of changes from April to June). However, for the same months there is an increase (notably for RCP8.5) reaching 40% (in May and June) over the mountainous regions of Myanmar, this will have a direct effect on the hydropower potential in this country.

Moreover, Tibetan glaciers in China are the source of the Mekong River (running through Myanmar, Laos and Cambodia). The glaciers at the Myanmar-Chinese border feed the Myanmar's largest river and most important economical waterways (Ayeyarwaddy, Chindwin, Sittaung and Thanlwin). All these glaciers are retreating faster than expected under present climate conditions and are likely to be affected substantially by climate change in the future; these storages are extremely important in sustaining seasonal water availability in the three countries from the river basins starting in this region.

Finally, climate model simulations show wide disagreements in projected changes in the amplitude of future El Niño events. ENSO influences the monsoon variability in South East Asia, a relationship which is also poorly understood, contributing to uncertainty in climate projections for this region in relation to the strength and length of the monsoon.

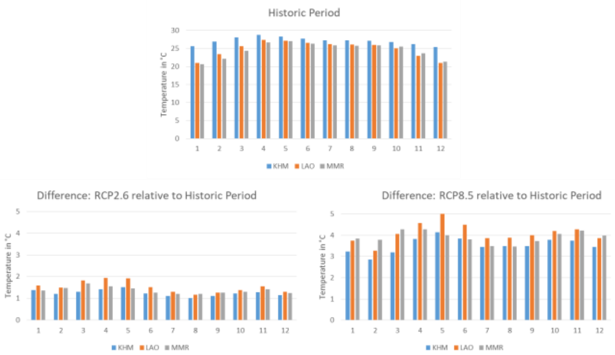


Fig. 1. Variation of temperature: Top - monthly mean temperature for the historic period for the 3 countries. Bottom - temperature difference at the end of century relative to the historic period for each RCP (left = RCP2.6; right = RCP8.5) in °C. (KHM=Kambodia, LAO=Laos and MNR=Myanmar)

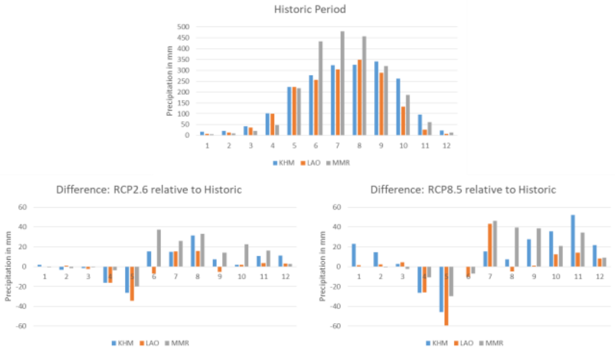


Fig. 2. Monthly mean precipitation (top) historic period for the 3 countries and bottom temperature difference (end of century RCPs minus historic) for the 3 countries in mm (left = RCP2.6; right = RCP8.5).

3. HYDROPOWER

3.1 Hydropower electricity system in the region

Hydropower is an important renewable energy resource for countries through which the Mekong River flows. The river's mainstream and tributaries are central to Laos' agriculture and hydropower sectors (ADB, 2019; FAO, 2020). Myanmar is less dependent on the Mekong for its water resources, and its vast hydropower potential largely draws from the basins of its Ayeyarwady, Chindwin, Thanlwin, and Sittuang rivers (Saw and Ji-Qing, 2019).

With only a low to modest proportion of each of the case country's technical hydropower potential currently exploited (Table 2), and high levels of electricity required to power their rapidly growing economies, hydropower has been central to power sector planning and recent projects. As at 2017, Myanmar had 69 hydropower projects that were at various stages of development, totalling over 43,000MW (IFC, 2017); Laos similarly had 12,000MW in hydropower projects under development (ADB, 2019). Limited generation alternatives to hydropower are largely based on coal; in addition to natural gas (Myanmar), diesel (Cambodia), and other renewables to a negligible extent (MME, 2015b; EAC, 2018; ADB, 2019).

Table 2. Hydropower in the case countries. Source: ADB (2016), IFC (2017), ADB (2018a), and ADB (2019).

Country	**Installed capacity (MW)**	**Technical potential (MW)**	**Share of electricity mix (%)**	**Electricity imports (GWh)**
Cambodia	1,878	10,000	52	1,440
Lao PDR	5,172	23,000	73	~7,500
Myanmar	3,331	100,000	60	0

By 2030, the Laotian government plan for 80% of installed capacity for domestic service to come from hydropower (ADB, 2019). The 2015 Myanmar Energy Master Plan envisaged a 2030 power supply mix of 57% hydropower, 30% coal (current coal consumption is largely imported), 8% natural gas, and 5% from other renewables (MME, 2015b). More recent government considerations include the replacement of coal for imported liquefied natural gas (ADB, 2016). The Cambodian government plan for a 2030 dependence on hydropower that is similar to the level in 2017 (~50%); with plans to displace diesel power plants with more (imported) coal and natural gas – the latter from reserves in offshore Overlapping Claims Area with Thailand (ADB, 2018a; Nguon, 2018).

An energy future highly dependent on hydropower production is not without security concerns. As a result of the natural hydrological cycle, both Laos and Cambodia require electricity imports to offset dry season shortfalls in hydropower generation (EAC, 2018; ADB, 2019). Under planned projects, Laos' hydropower capacity is soon expected to meet dry season demand. However, the effects of a changing climate on the occurrence of extreme events such as droughts, creates uncertainty in potential monthly/annual production and cost-benefit of what are capital-intensive infrastructures, and what adaptation and resilience measures are needed to optimally safeguard future electricity supply. These risks are highlighted by the fact that some of Laos' hydropower power plants have recently had operating capacities as low as 15% (ADB, 2019).

3.2 Hydro potential under climate change - Method

As for the climate data presented in the Section 2 we use data from the ISIMIP inter-comparison project for the hydro-generation potential change under climate change conditions.

This is computed using the methodology implemented in Gernaat et al (2017). Accordingly, three categories of potentials are defined: full potential, remaining potential and remaining ecological potential. Within each of these potentials, a further distinction is made between technical and socio-economic potentials. We extracted the ecological socio-economic potential from the database for the historical period and 2 RCPs chosen for the climate analysis: RCP2.6 and RCP8.5.

Two different kinds of hydropower technologies are included. First is the river power plant, which harness energy mainly from the flow of the river (Run of Rever) and the head created by a dam. They have medium to high storage potential and some water reserves to serve medium to peak electricity load. Second is the diversion canal power plant, which is often found in mountainous areas, characterized by a water inlet at higher elevation diverting river water through pipes to a power station at lower elevation. These systems have no dam and therefore no storage capacity.

The analysis on the effect of climate change is assessed using five different global hydrological models (GHMs: LPJmL Sitch et al. 2003, VIC Hamman 2018, MPI-HM Stacke and Hagemann, 2012, WBM Wollheim et al. 2008 and PCR-GLOBWB Sutanudjaja 2018), and the four global climate models (GCMs) used in the previous part from the ISIMIP project. The analysis quantifies climate-impacted global energy potential from hydropower, solar, wind and biomass energy sources. This analysis therefore looks at the direct climate change impacts on potential hydro generation supply. Four categories of potentials, or a minor adjustment of these, are established: theoretical, geographical, technical and economic potentials.

Theoretical (available) potential: the theoretically upper limit that can be produced at the total earth surface of the primary energy source under consideration

Geographical potential: the theoretical potential at land area available for the production of the energy source under consideration (removing protected or urbanised land for example).

Technical potential: the geographical potential reduced by losses due to the process of converting primary energy to secondary energy carriers.

The economic potential: the technical potential that can be realized at profitable levels, depicted by a cost-supply curve of secondary energy.

As mentioned, we analyse the latter.

Hydropower energy calculation potentials within the ISIMIP project

The **full potential** is computed assuming that each river was unused and undisturbed.

The **remaining potential** is computed by excluding areas already covered by existing dams and reservoirs, based on the GRanD database (Lehner et al. 2011).

The **remaining ecological potential** is computed similar to remaining potential, assuming that all hydropower stations release at least 30% of the natural monthly discharge to maintain natural river flow throughout the year (Gernaat et al. 2017).

The global technical and economic hydropower production potentials of river power plants and diverstion canal power plants are computed and analyzed to derive cost-supply curves for the hydropower source. Cost-supply curves describe the potential availability of the energy sources at different costs levels, and/or how primary resources are converted to secondary energy carriers at a given efficiency and cost (including capital, operation, and maintenance costs), for use as input into energy system models and Integrated Assessment Models (IAMs).

Regional cost-supply curves are developed based on estimates of various constraints on theoretical potentials, in combination with existing and future cost estimates. Shared Socioeconomic Pathway (SSP) scenarios are used to explore the long-term cost-supply developments, under both baseline and climate policy scenarios (Riahi et al. 2016, Van Vuuren et al. 2016). For this experiment, the cost-supply curves are computed under the baseline SSP2 (‘middle of the road’ socioeconomic development).

Hydropower method:

1. compute/acquire -30-year average, global monthly total runoff dataset from five GHMs times four GCMs combinations;
2. subtract water demand from agriculture, residential, industry and other sectors (excluding hydropower generation);
3. identify potential hydropower dam site at every 25-km river interval in each basin;
4. determine reservoir size and flooded land area, for each potential dam site;
5. calculate the costs of agricultural land loss and population displacement caused by reservoir development;
6. use high resolution Digital Elevation Model (DEM) to determine dam height and width;
7. estimate number of people displaced using SSP2 population projection (for future) and historical population maps (for historical simulation) ;
8. calculate cost of agriculture land loss caused by reservoir construction based on land value for potential agricultural yield map;
9. calculate the distance (km) between a potential hydropower site and its nearest power line;
10. use the distance in combination with local turbine capacity as input in a power line allocation scheme, and calculate the investment costs of building new transmission lines;
11. exclude protected areas by overlaying map from the World Database of Protected Areas (WDPA) to get remaining potential; and
12. reduce the discharge further by 30% to account for remaining ecological potential.

3.3 Results

Figure 3 presents the location of the hydropower stations over the 3 countries as calculated from the above method. Only power stations having an output above 100 GWh/y are plotted. It is clear that most of the potential in the region analysed resides in Myanmar (445 for Myanmar). Laos and Cambodia come largely with a lower number of potential locations for hydropower (115 for Laos and only 25 for Cambodia). The number of potential locations will also have a strong impact the potential outputs for climate change effects on hydropower in the future.

In Myanmar, the geographical distribution is mainly concentrated in the Ayeyarwady, Chindwin, and Thanlwin river basins with larger power stations. Laos shows a smaller number of smaller power stations over the lager basins of Nam-Ngum, Nam-Nhiep and the South Xe-Kong. Cambodia's potential is limited to the Cardamom Mountain and the region bordering Laos.

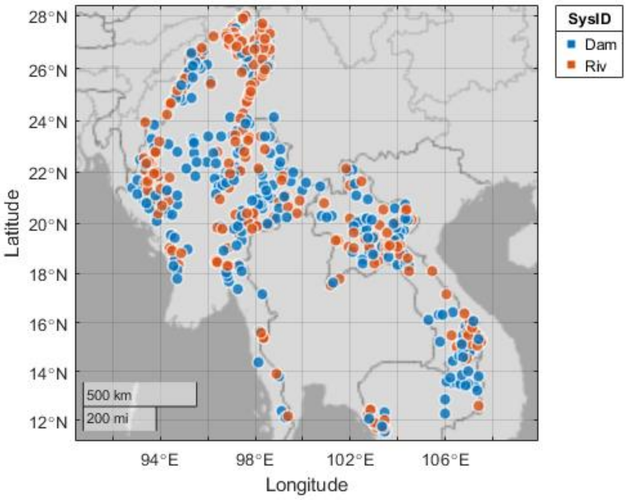


Fig. 3. Geographic locations of the two hydropower systems. Blue indicates position for power generation from the river power potential (with dam), red indicates the diversion canal power potential. The presented locations have potential over 100Gwh/y.

The changes in hydropower production potential for the three countries are presented in Figure 4 as cost curve changes for potential cumulative production per year at national level. We observe two different behaviours in terms of response to climate change in the three regions. Cambodia and Laos present a clear decrease in output for a specific cost level (a maximum decrease of 20% for RCP8.5). In contrast, Myanmar shows an increase in generation under climate change for each specific cost level (the maximum increase occurs under RCP8.5, reaching over 30% of the historical potential). The maximum production is also larger for Myanmar by an order of magnitude (plateauing around 0.4 PWh/y corresponding to power availability about 85,000MW) than for the two other countries (0.06 and 0.01 PWh/y or 13,800 and 2.,300MW for Laos and Cambodia respectively). The reduction in Cambodia or Laos under RCP8.5 condition can reach 20% of maximum capacity corresponding to the loss of 2,760MW for Laos or 460MW for Cambodia. However, the potential increase 30% in Myanmar would increase potential or decrease cost of electricity generation for the same capacity installed. Reader should be cautious on these figures as these are the changes at national level. The picture could be different if the analysis were carried out at individual basin levels in these countries.

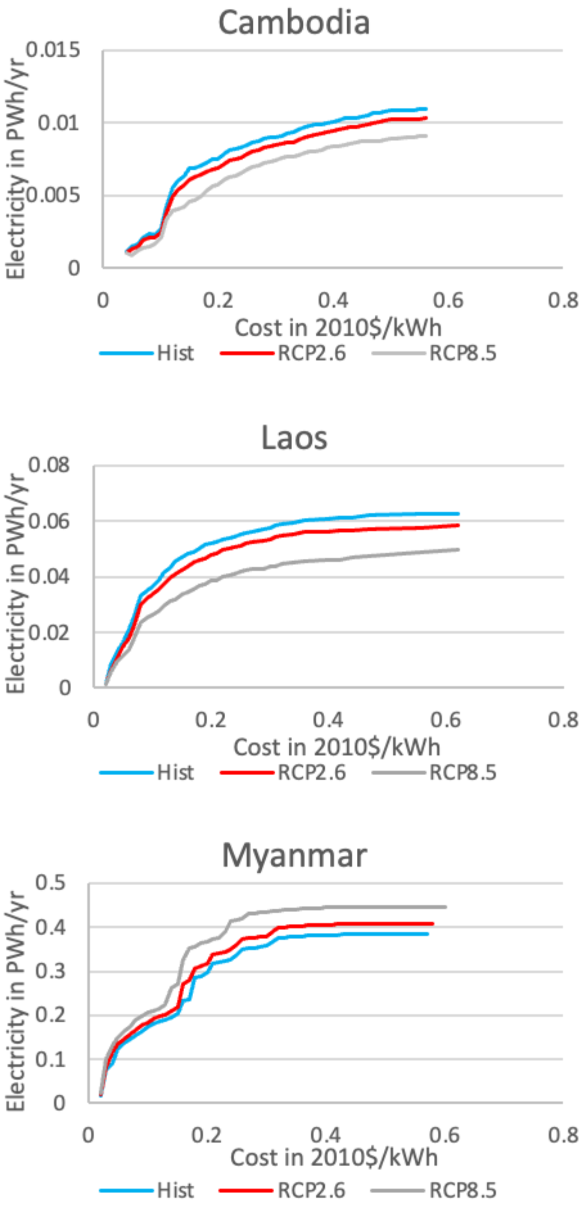


Fig. 4. Cost curves for the potential of hydrogenation for the three countries (X-axis is cost in 2010$/kWh and Y-axis is electricity production in cumulated PWh/y). 2070 to 2100 period for the two RCPs.

Climate change over the period can explain some of these differences in term of change in annual precipitations. Globally the RCP2.6 and RCP8.5 end of the century presents an increase in annual precipitation in Myanmar and Cambodia but a slight decrease over Laos as seen in Figure 5. The difference lies in the modulation of the precipitation over the seasons and the type of hydropower plants the region allows to develop (orography mostly). As previously mentioned, two types of plants are represented in the hydropower modelling methodology: with and without storage. A plant with storage is less impacted by seasonal modification as it can store water to compensate reduced seasonal precipitation or increased evapotranspiration (due to higher temperature). The difference in response for the Myanmar case can be explained by the fact that over the high-altitude regions in

Myanmar (mountains neighbouring Tibet region) the precipitation difference shows an increase compared to historical levels in the pre-rainy season (particularly noticeable in RCP8.5). This wetter pre-rainy season, creating larger snow packs to melt and supply river flows later in the year, increases output from dam and diversion canal (with no reservoir) with a noticeable increase for RCP2.6 and large increase for RCP8.5.

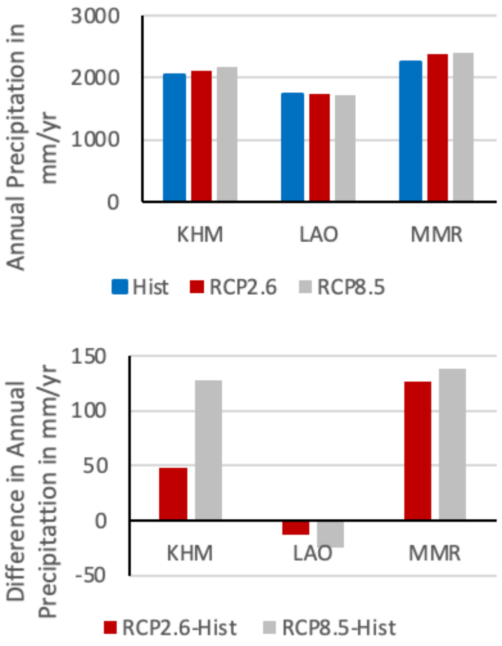


Fig. 5. Annual precipitation for the historical and the end of century 2 scenarios (top); and change compared to historical period for end of century RCP2.6 and RCP8.5 (bottom) in mm/y.

4. LAND USE AND AGRICULTURE

4.1 Land and agriculture in the region

Agriculture is a very important sector within the focus countries. Farming is the primary occupation of the rural areas within each country. Nearly 80 percent of the region's population lives in rural areas where subsistence agriculture, fisheries, and forest extraction are the main economic activities. Agriculture accounts for 63% of total employment in Laos, 34% in Cambodia, and 50% in Myanmar. In Cambodia, Laos and Myanmar the sector is currently less intensively developed and modernised than in neighbouring countries (Thailand, Vietnam or China). Laos' mountainous and hilly topography means only about 10% of land area is used for agriculture (ADB, 2018b), making land use optimisation important to productive cropping over time.

Rice dominates crop production in all three countries, particularly in the lowland areas. In the uplands or highlands of all the countries, farmers in the past, especially ethnic minorities, practiced shifting cultivation. However, the agricultural practice has recently changed to increase annual and perennial economic/industrial crops, such as upland rice, maize, potato, cassava, but also sugarcane, coffee, tea, or cashew but these crops do not compare with rice in terms of production, yield, and significance as a local food source (IWRP, 2015).

Statistics from the FAO (Table 3) show that cassava, groundnut, maize, rice, soy and sugarcane are the most prominent agricultural crops in the region. Furthermore, the FAO 2017 database (not presented here), shows that for sugar cane, rice and cassava the export of crops are important sources of external revenue for the countries.

Table 3. 2017 FAO statistics on harvested area (km2) for specific crops.

Crops	Cambodia		Laos		Myanmar	
	Rank	Area	Rank	Area	Rank	Area
Rice	1	2966487	1	956134	1	6745375
Cassava	2	280945	3	70930	26	34703
Maize	3	156380	2	207190	6	500605
Groundnuts	11	18000	8	18887	4	1033942
Soybean	4	104000	17	4260	17	139736
Sugar Cane	9	26504	6	29090	15	163248

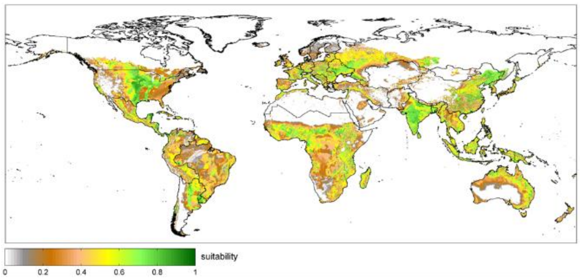
Myanmar was the largest exporter of rice in the world during 1950s (Than 1990). Now, it is middle-level rice producers in world ranking, but the government is keen on increasing output over the coming decade, as the potential is high for the land and water rich country, with a goal to become a major exporter within South East Asia. Cambodia and Laos in comparison are minor producers, though both have also ambitious plans to increase crop yields and production to enable greater export potential. Rice yields vary enormously throughout the region. The highest rice yields seen in Myanmar can be more than double the yields in Laos or Cambodia (the lowest) (Mutert 2002). The divergence is generally associated with different farming management such as levels of acreage under irrigation, varieties sown, and technology applied (fertilizer, pesticides) (Mutert 2002).

We choose to model study the land suitability results under climatic changes for six crops on the basis of data presented in Table 4 and the importance of the export: cassava, groundnut, maize, rice, soy, and sugarcane.

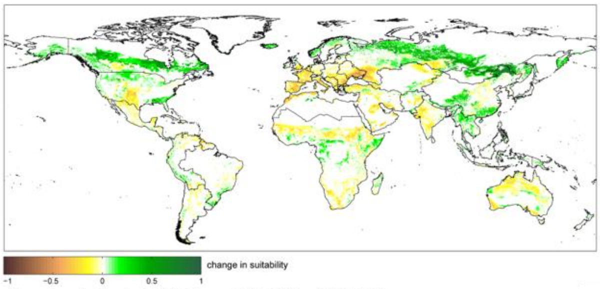
4.2 Crop land suitability under climate change - Method

We use the fuzzy logic land suitability model originally created by Zabel (Zabel et al 2014) and further developed recently by Cronin (Cronin et al 2020) to calculate the suitability of the land to support growing crops as well as to investigate how the climate changing could impact this. Structure of the model can be found in Zabel et al. (2014) and the specific method that produced these model results is fully described in Cronin et al. (2020).

The model is global and indicates the spatial distribution of suitable cropping areas with relatively low computational requirements. The model can explore the suitability for crops under historic and future climatic conditions, as presented in figure 6. The model derives the suitability of each grid cell for each crop by comparing global gridded data sets of climate, soil and topographic conditions to a set of requirements specific for each crop. The crop requirements are represented as 'membership functions' for the mean temperature and total precipitation over the growing season, slope and the following soil properties: texture, proportion of coarse fragments, proportion of gypsum, base saturation, pH, proportion of organic carbon, salinity and sodicity. Values for the membership functions are drawn from Sys et al. (1993).



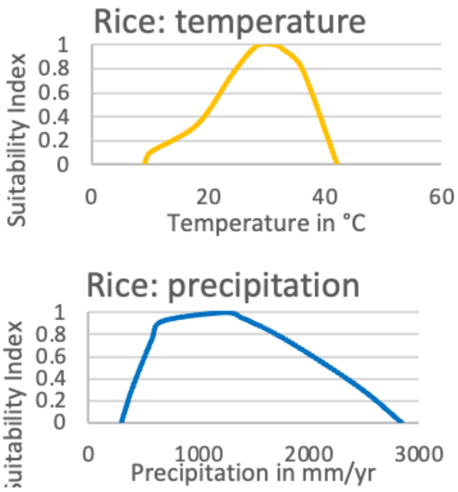
Agricultural suitability considering rainfed conditions and irrigated areas (1981–2010). (Zabel 2014)



Change in agricultural suitability between 1981–2010 and 2071–2100.

Fig. 6. Extract from Zabel et al., 2014 – agricultural suitability and changes in suitability due to climate change for the end of 21st century.

Three shapes for the suitability function are possible: ‘more is better’, ‘less is better’ and ‘optimum’. For temperature (e.g. given in figure 7), the suitability is increasing from a minimum towards an optimal temperature and again decreasing until a maximum temperature is reached. Eight soil parameters are considered: texture, proportion of coarse fragments and gypsum, base saturation, pH content, organic carbon content, salinity, and sodicity (or amount of sodium). Terrain is considered by the slope, figure 7 provides a slope suitability function representing the ‘less is better’ with zero suitability for all crops above 15% incline. The fuzzy-logic approach calculates fuzzy values based on the ecological rules (between 0 and 1), which determine the crops’ suitability in a specific location. The suitability is effectively limited by the lowest membership value of all parameters.



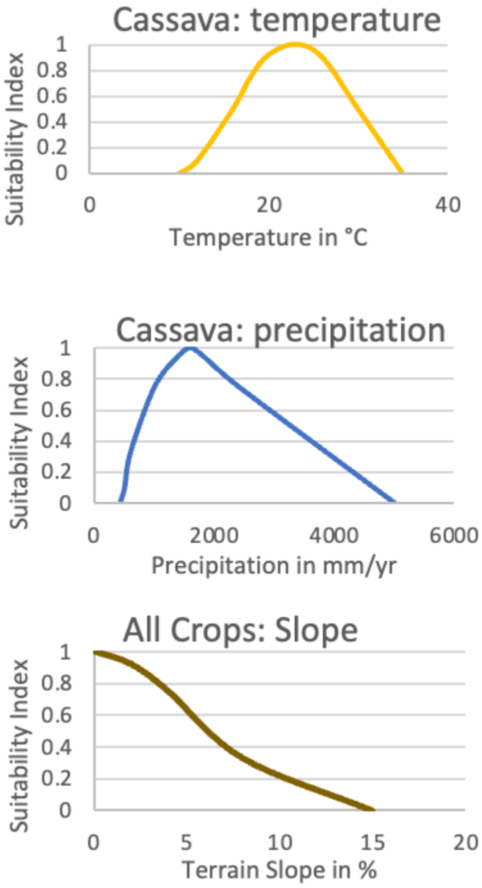


Fig. 7. -Four top panels = climatic suitability function for rice and cassava (temperature and precipitation); bottom panel = slope suitability function for all crops. X-axes: specific variable unit (°C for temperature; mm/y for precipitation; % for slope) y-axe: suitability index from 0 to 1.

To test the suitability according to the climatic parameters, the model takes a year of daily precipitation and mean temperatures from the climate model results from each GCMs included in the ISIMIP database. Starting at the first of January and shifting the start date by one day at a time, each possible growing period during the year is tested for suitability, according to the mean temperature, total precipitation and four other minimum requirements during that period. These additional requirements are 1) there must be at least 20 mm of precipitation within the first 14 days of the growing period, 2) no day can have an average temperature below a specific temperature, and 3) the mean annual temperature must exceed 0°C. Each day of the year is assigned a climate suitability score, which is the minimum of the temperature and precipitation suitability scores (taken from the membership functions) for the growing period starting on that day. The overall climatic suitability for each grid cell is the maximum climatic suitability within the year (and the day this value corresponds to is the optimal start of the growing season).

The soil suitability is the minimum of the suitability scores for the individual soil variables, which do not change with time. The overall suitability is the minimum of the soil, climate and topography suitability scores. Thus, the overall suitability for each grid square is effectively determined by the least suitable parameter. Note that the model extracts the technical, rather than economic, potential for each crop.

Full details of the model structure are given in Zabel et al. (2014) and the specific modelling method that produced these results is described in Cronin et al (2020). The land suitability model is run at 30 arcsec resolution (approximately 1 km at the Equator) in in order to capture localised soil and climatic conditions and local interactions between climate change impacts and land-use, as well as possible with the available input.

The land suitability model is run with climate data representing 30-year averages of the historic period and three future periods, however in this report we will focus only on the period over the end of the 21st century, for the 2 greenhouse gas emissions scenarios chosen in this study: RCP2.6 and RCP8.5. The land suitability results are averaged over the climate models to create an ensemble mean.

The model was run so as to represent current irrigated conditions. Currently irrigated areas were identified from the Meier 2018 dataset (Meier et al. 2018), which indicates the percentage of each grid cell currently equipped for irrigation. In irrigated grid cells, the model was run without the precipitation parameter, so that precipitation placed no limit on the suitability. It was assumed that irrigated areas remain unchanged through the century.

4.3 Results

Suitability maps for the historic period are presented in figure 8 for the six crops. In general, limiting conditions for land suitability are mostly decided by soil and topography: good suitability for Central Cambodia, Central Myanmar and the Irrawaddy delta. The low suitability over Laos is due to its mostly mountainous topography. Maize and sugarcane have very high scores in Central Cambodia and the Irrawaddy delta as neither soil nor climate are limiting in these regions; the same behaviour is seen for soy and groundnut. These regions are high value areas for agriculture. Central Myanmar has reasonable scores (around 50) for most of the crops but rice. Rice shows very low suitability all over the region due to soil conditions (up to 50 only) however the model doesn't represent paddy field (specific fertilizer amendments and topography managements: i.e. reducing slope by the construction paddy fields in terraces). Inner tropics have adequate temperature and moisture throughout the year for rice, but soil quality often restricts cultivation due to low organic content and acidity (Ramankutty et al. 2002).

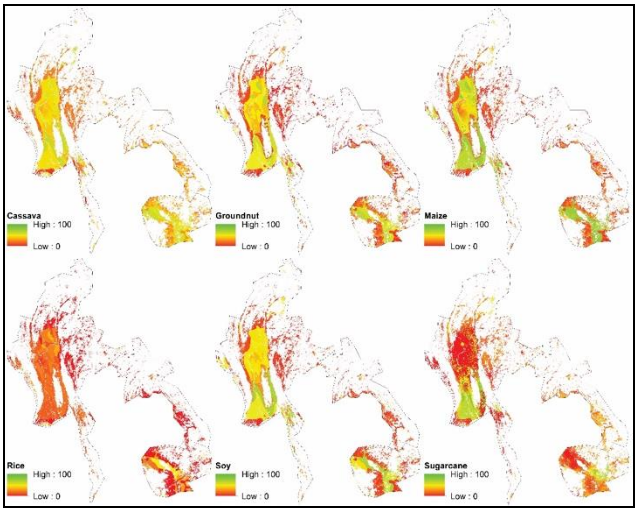


Fig. 8. Suitability index (from 0 to 100) for historic conditions (taking into consideration land and climate conditions) for the 6 crops

Figure 9 presents the suitability difference between RCP2.6 (end of the century) and present period scores and figure 10 presents the second climate scenario under RCP8.5. Only climatic conditions are modified; there is no change in other parameters (soil quality or farm management). In a separate stage, the "land and topology" limitations are removed to extract only the effect of changing the climate in the suitability results. This is necessary to isolate the changes due to climate without limitation of soil quality or slope steepness as the fuzzy logic model only extracts the lowest suitability score from land and climate parameters. Figure 11 presents these results for rice for present day suitability and the changes under the two climate scenarios, in this result, the soil and topology suitability are not taken into account – once again high yields rice production occurs in paddy fields in highly controlled conditions in the important lowland areas in the 3 countries; the soil suitability limitation from the model is not properly representing these agricultural management techniques. The following paragraphs describe the changes in suitability seen for areas that are currently important for agriculture.

Similar changes in suitability are seen for the six crops, with some notable differences. Some large areas with negative impacts (reduction by 20 to 30 in the suitability score) points in the very high scores seen in the present conditions due to changes in water availability and optimum temperature are seen for soy, groundnuts. Cassava and maize also present large areas with reduction in suitability in some agricultural regions of Myanmar and Cambodia, but improvements are noticeable (up to 30 suitability points) over the Central part of Myanmar and the Cardamom Mountain region in Cambodia. In very dry area of Central Myanmar, the reduction in suitability is driven by the change in the wet season start date as seen in the climatic analysis but this represents improvements from a relatively low present suitability for agriculture. Rice also shows an increase in suitability over these two regions. Worryingly, under RCP8.5 conditions in figure 11, increase in suitability for rice occurs where rice suitability scores lower (central Myanmar) but there is a decrease in the suitability of rice (about 15 suitability points) driven by climate change in the Irrawaddy delta and to a lesser extent in South East Cambodia – areas of high yields and production for the region. Finally, the improvement seen for sugarcane over Central Cambodia and around central Myanmar is where sugarcane is produced.

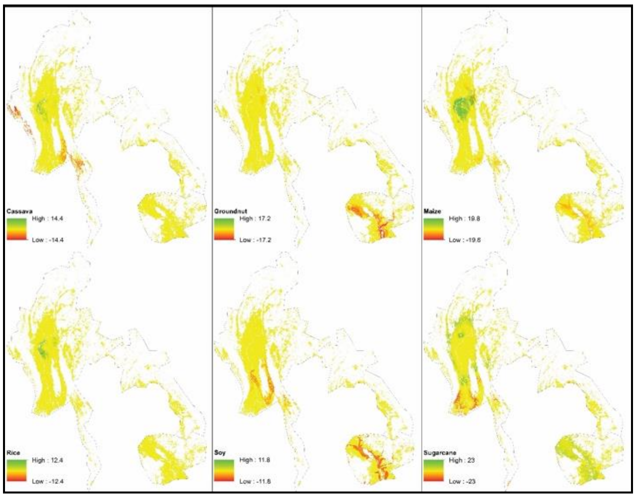


Fig. 9. Difference in land suitability level between present day climatic conditions and future conditions under RCP2.6 pathway for the 6 crops.

Figure 10 presents the results for RCP8.5, the most extreme climate change scenario with the largest temperature changes. As before only the climate suitability is taken into consideration in these results. Mostly the same conclusions can be drawn but larger negative impact are noticeable in term of area with shrinking surface showing positive response in suitability (clearly observable for cassava in Central Region of Myanmar). In this scenario of strong climate change, the negative impacts on the suitability score can reach 40 to 60 suitability points.

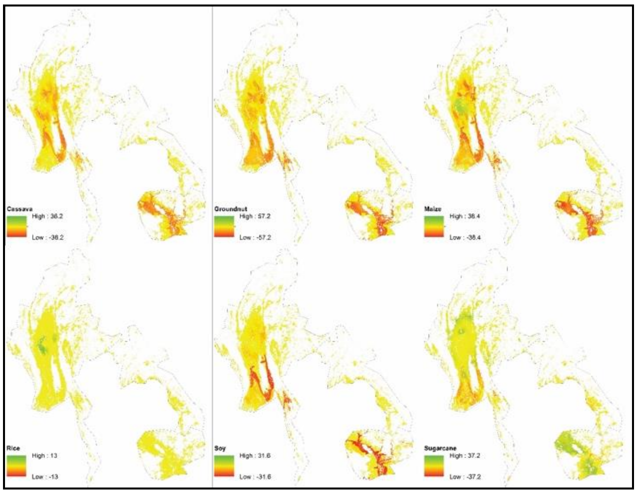


Fig. 10. Difference in land suitability level between present day climatic conditions and future conditions under RCP8.5 pathway for the 6 crops.

From the gridded results, it is clear that the land suitability for agriculture decreases under RCP8.5 in comparison to RCP2.6. However, if the geographical representation of the change in suitability for a crop, as presented above, is useful when analysing a specific region or limited area, it is less practical to draw a larger picture at national level as for some crops negative and positive effects on suitability are observed.

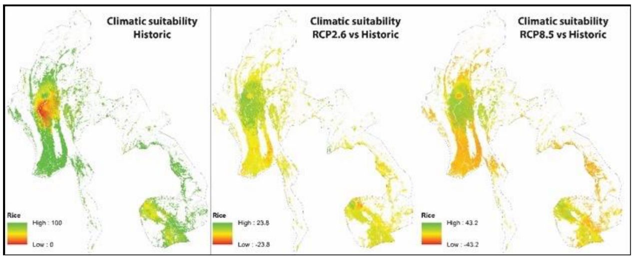


Fig. 11. Climatic conditions only suitability (first panel) and difference in climate suitability level between present day climatic conditions and future conditions under RCP2.6 and RCP8.5 pathway (middle and last panels respectively) for rice.

6. CONCLUSION

This study analysed the impacts of climate change on water availability for hydropower and land suitability for agriculture production in the least developed countries in the Greater Mekong Sub-region, namely, Cambodia, Laos and Myanmar. It used a range of publicly available data coming from various global models (GCMs) to quantify the impacts on hydropower. Further, it used global Fuzzy Logic Land Suitability Model to quantify the impacts of climate change on land suitability for various crops in the three case study countries.

The analysis shows that there are differences in the impacts of monthly precipitation and hydropower across the three countries under RCPs compared to historical data. Regionally, it is noticeable that over the high altitudes of Myanmar the end of dry season (April to June) are wetter. Quite significant changes in hydro-generation potential can occur depending on the region: Laos and Cambodia show decrease when Myanmar shows increase in output potential between present and RCP2.5 and RCP8.5 respectively. Climate impacts on land suitability are stronger for RCP8.5 than RCP2.5 (as expected). Quite significant increases or decreases in land suitability can occur depending on the region and the crop. Further, Rice crop is adapted to climatic conditions in the region and it seems that climate change as assessed in the model is not detrimental to rice suitability even under RCP8.5 climatic conditions.

Limitations

The climate data combine only long term mean changes in temperature and precipitation without incorporating potential changes in extreme event affecting the two sectors (change in strength or in occurrence probability of extreme events). These extreme events are increasing climate vulnerability for agriculture and hydro-power stations.

Competition between hydrogenation and agriculture for land or water as well as competition between crops (food security or economic growth via export) is not included in the study.

The suitability index for agriculture calculated is not including economic consideration, as we didn't study the suitability thresholds when farmers stop growing specific crops. Management and farming techniques or crop improvements are not taken into consideration as the suitability functions are fixed. The soil erosion and degradation (nutriment leaching) that can be exacerbated by climate change are not included in the study.

Finally, acceptance by local community of large hydro development or large area of monoculture for export crops may also challenge the development of these sectors.

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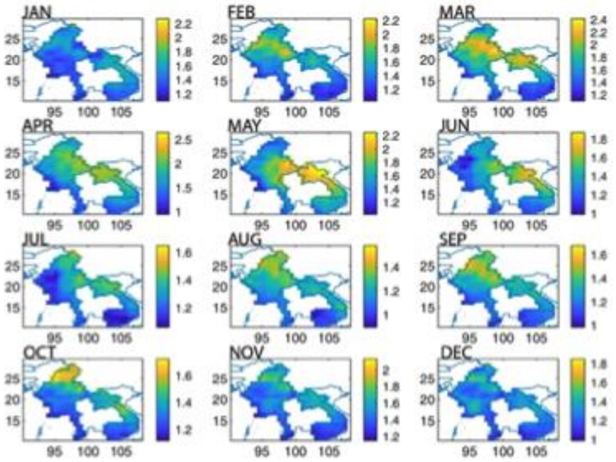
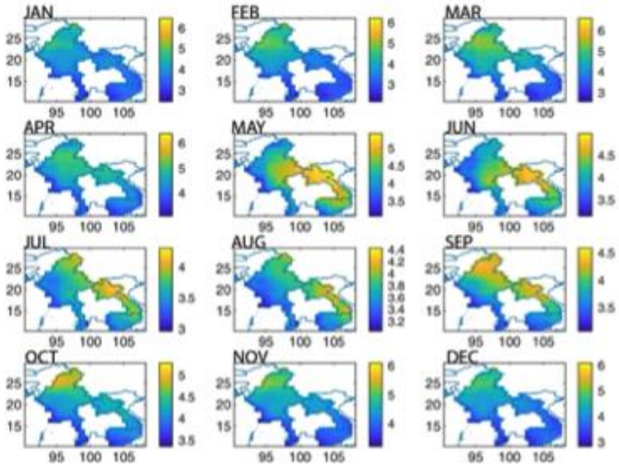
APPENDIX

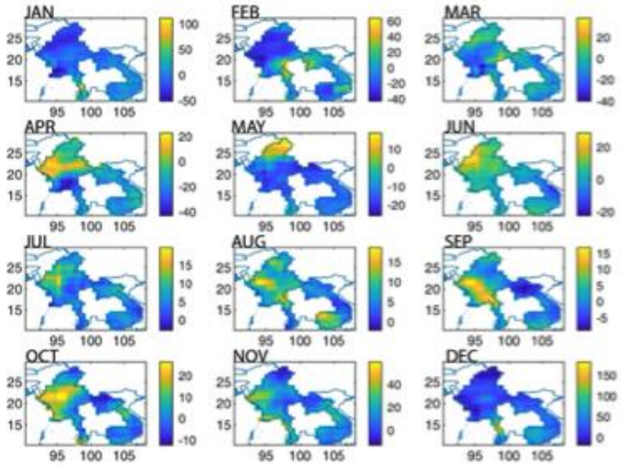
Appendix 1: monthly mean temperature difference in °C between RCP2.6 and historical period.



Appendix 2: monthly mean temperature difference in °C between RCP8.5 and historical period.



Appendix 3: relative monthly mean precipitation change between RCP82.6 and historical period in %).



Appendix 4: Figure 8: relative monthly mean precipitation change between RCP8.5 and historical period in %.