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Climate Change Impact Assessment on Water and Agriculture in Cambodia as Part of the Water-Climate-Agriculture Workbench

So Im Monichoth, Kumiko Tsujimoto, Shizu Yabe, and Petra Koudelova[1]

[1]Corresponding Author

The University of Tokyo, Japan

Email: petra@hydra.t.u-tokyo.ac.jp

ABSTRACT: Building resilience to climate change and variability is essential for achieving sustainable development. In Cambodia, the economy depends on agriculture, mainly rice production. As most rice fields are rainfed and most farmers rely on their non-science-based experience, they are unwilling to adjust to changing rainfall. The aim is to provide information related to the changing water cycle, which could be used by local governments and farmers to adjust crops, planting time and water resources management accordingly. In this study, a hydrological model and rice growth model were coupled into a "Hydro-Crop" model and used to integrate satellite and in-situ data and general circulation model (GCM) outputs of CMIP3 to generate the desired information. In this manner, the hydrological conditions, optimum planting dates and yield for present and future climate were obtained and the results were compared with the actual situation.

KEYWORDS: *climate change and food security - Cambodia, rice yield simulation, SAFE, AWCI, water cycle integrator*

Introduction

Building resilience to climate change and variability is essential for achieving sustainable development of Earth's societies and ecosystems. To accelerate the coordinated and integrated efforts towards this goal, the "GEOSS Water Cycle Integrator (WCI)" recognises fundamental linkages among water, land use, carbon cycle and ecosystem services, and food-, energy- and health-securities. In this context, WCI is aimed at developing effective means for sharing coordinated, comprehensive and sustained water cycle and related Earth observations and information for sound decision making. The GEOSS Asian Water Cycle Initiative (AWCI)—a regional collaborative framework of 18 Asian countries—adopted the WCI approach under the featured project (ARCP2013-11CMY-Yabe) and has initiated and advanced development of so-called workbench functions in AWCI countries. (A workbench is a virtual geographical or phenomenological space where experts and managers work together to use information to address a problem within that space). The pilot case of a fully functional workbench has been developed in Cambodia under cooperation among stakeholders, space agencies and science communities on water, climate and agriculture. The resulting integrated system provides on-line information on near-real time spatial precipitation, soil moisture as well as rice production to local communities and technically is supported by DIAS and the University of Tokyo. The presented study was carried out as a part of a Space Application For Environment (SAFE; http://www.eorc.jaxa.jp/SAFE/index.html) prototyping activity and a part of the AWCI activities in Cambodia and contributed to the workbench development. It was published in Monichoth et al., 2014.

HIGHLIGHTS

- Workbench function establishment for Water Cycle Integrator (WCI) approach towards building resilience to climate change in AWCI countries.
- Water-Climate-Agriculture workbench in Cambodia through cooperation with stakeholders (Ministry of Water Resources and Meteorology, Cambodia, MOWRAM; Tonle Sap Lake Authority and local province authorities), AWCI–DIAS and JAXA–SAFE.
- River Management System development in AWCI countries.
- Capacity building for WCI approach (data integration, climate change assessment methods, river management system).

The economy in Cambodia depends on agriculture with rice being a major agricultural product. However, no significant irrigation system is available and thus most of the rice fields depend on rainfall and streamflow, which makes the farms greatly vulnerable to climate change. Earlier studies have suggested that variability of rainfall and streamflow would be greater due to climate change. Accordingly, an assessment of climate change impacts on rainy season onset and hydrological regime in Cambodia is essential for farmers' consideration of future cropping activities (variety of crops and optimum planting and harvesting times). The target area of this study, western Cambodia, has the largest rice production and most land rainfed. For their cropping decisions, farmers rely on their experiences and thus would have difficulties to adjust to changing rainfall and hydrological patterns, which could cause severe food production losses in the region. At the same time, there is no operational system for climate and weather data collection, and thus it is difficult to obtain reasonable initial atmospheric conditions for the forecast and/or prediction of future atmospheric conditions. The aim is, therefore, to provide such information related to the changing water cycle, which could be used by local governments and farmers to adjust crops, planting time and water resources management accordingly. In this study, a hydrological model and rice growth model were coupled (resulting into a "Hydro-crop" model) and used to integrate satellite and in-situ data and general circulation model (GCM) outputs to generate the desired information. In this manner, the hydrological conditions, optimum planting dates and yield for present and future climate were obtained and the results were compared with the actual situation.

Methodology

The overall framework of the study is shown in Figure 1. The coupled distributed hydrologic and rice-growth model Hydro-Crop

(Tsujimoto et al., 2013) used in this study was developed by combining the Water and Energy Budget Distributed Hydrological Model (WEB-DHM; Wang et al., 2009) with a paddy-field scheme and the Simulation Model for Rice-Weather Relations (SIMRIW)-rainfed model (Homma and Horie, 2009). The Hydro-Crop model dynamically couples the modified WEB-DHM and SIMRIW-rainfed and was validated for the Sangker River basin, which is the target basin of this project (Tsujimoto et al., 2013). In this model, parameters such as planting date, irrigation amount and timing, soil characteristics and fertiliser amount may be fully distributed, temporally and spatially. The target rice type for obtaining the parameters and model analysis is IR64 (short-term rice).

Firstly, the forcing data for present and future climate were prepared for the Hydro-Crop model from the GCM output using the set of 24 GCMs of the of the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3; Mehl et al., 2007). Instead of using the output of all 24 models, only

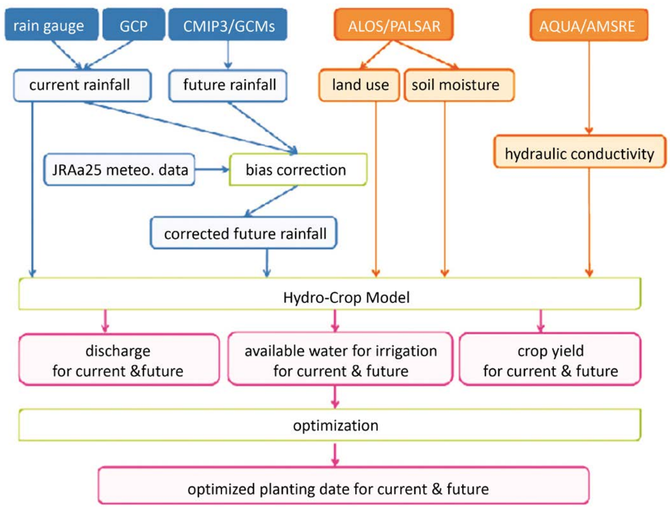

Figure 1. The overall framework of the study.

six models that could reproduce seasonal evolution of the monsoon in Cambodia (May to October) in the baseline period (1981–2000, i.e., present climate) were selected based on criteria described in Monichoth et al. (2014). The precipitation bias in the GCM output was corrected using the statistical method developed by Nyunt et al. (2013).

Secondly, the initial conditions and soil and land-related parameters (land use, soil hydraulic conductivity and initial soil moisture) for the Hydro-Crop model were prepared using the satellite data of ALOS/PALSAR (land use, soil moisture) and Aqua/AMSRE (hydraulic conductivity). The hydraulic conductivity was optimised by using Land Data Assimilation System developed at the University of Tokyo (LDAS-UT). Thirdly, the obtained initial conditions, model parameters and forcing data were inputted into the Hydro-Crop model and the model was run for the present climate (1981–2000) and the future climate (2046–2065) periods. Hydrological and rice production results were analysed and optimised planting dates for present and future climate conditions were calculated using the method of Ohta et al., (in preparation).

Data

The environmental data used in the study is presented in Table 1.

Results and Discussion

GCM selection procedure resulted in a set of six model outputs that were able to capture the rainfall pattern over the region of interest in May, June, July, August, September and October. These included: gfdl_cm2_0, gfdl_cm2_1, csiro_mk3_0, ingv_echm4,miroc3_2_hires, and miroc3_2_medres model outputs. Seasonal change of rainfall for the past and future are shown in Figure 2, which depicts bias-corrected, monthly-averaged future projected precipitation by GCMs and observed past precipitation.

The analysis suggests that monthly rainfall amounts do not change significantly in future but the six models have different trends. Two models – csiro_mk3_0 and gfdl_cm2_1 – provide greater amount of rainfall in future from February to September, i.e. rainy season would begin and end earlier than at present. The model gfdl_cm2_0 provides almost double the amount of rainfall in October but the rainy season ends in this month, i.e. as at present. The extreme increase in heavy precipitation at the end of the monsoon season indicates that larger floods may be expected. At the same time, the interannual variation is greater in future and thus we may also expect more severe droughts.

The simulation by the Hydro-Crop model for the year 2011 suggested that the best planting time for maximising crop yield was August (Monichoth et al., 2014), which is in agreement with the actual situation, i.e. the model gives reasonable results and may be used for future situation assessment. The results of future simulations are summarised in Figure 3. They revealed that some of the models provided a wide range of the best planting time, spanning the whole monsoon period in Cambodia (May to October). Three models – gfdl_cm2_0, ingv_echam4, and gfdl_cm_1 – indicated the best planting time at the end of September in 6 years over the 20-year period. In such cases, one more crop could be planted in May with the harvest prior to September. However, May planting carries a higher risk of low yield due to water shortage and thus irrigation would be strongly recommended. Depending on the irrigation possibility, farmers can decide to plant once or twice. The miroc3_2_hires and miroc3_2_medres models do not indicate any specific month as being the best for planting, only suggest planting from May to September, while the csiro_mk3_0 model indicates that July through September is optimal. In many cases, lack of sufficient rainfall from May through July causes significantly lower crop yield.

Data type or usage	Data source
GCM products	Coupled Model Intercomparison Project phase 3 (CMIP3), Mehl et al., 2007 (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php); 1981 – 2000 & 2046 – 2065.
GCM selection reference data	Precipitation: Global Precipitation Climatology Project (GPCP), 1981 – 2000 (http://www.gewex.org/gpcp.html). Geopotential height: Japanese 25-year Reanalysis (JRA25), 1981 – 2000 (http://jra.kishou.go.jp/JRA-25/index_en.html).
GCM rainfall bias correction	Rain gauge data at Battambang (103.21°E, 13.09°N; western Cambodia), 1981–2000.
Land use mapping	Advanced Land Observing Satellite (ALOS)/Phased Array type L-band Synthetic Aperture Radar (PALSAR) at dual polarization (FBD); 4 paths synthesized, September – October 2010 (Path 481, 8 October 2010; Path 482, 25 October 2010; Path 483, 26 September 2013; and Path 484, 13 October 2010). Provided by JAXA under the SAFE framework.
Soil moisture	ALOS/PALSAR at full polarization (PLR), 8 April 2011. Provided by JAXA under the SAFE framework.
Hydraulic conductivity	Aqua Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E) data (http://sharaku.eorc.jaxa.jp/AMSR/index.html January through March 2011, at 10.6 GHz and 36.5 GHz (vertical polarization).
LDAS-UT runs	AMSR-E (as above) Global Land Data Assimilation System (GLDAS) output (http://ldas.gsfc.nasa.gov/), 0.25° spatial resolution every 3 hours (GLDAS_NOAH025SUBP_3H), January through March 2011.
Hydro-Crop forcing	Six rainfall stations in the target, Sangker river basin JRA25 data (http://jra.kishou.go.jp/JRA-25/index_en.html)

Table 1. Data used in the study.

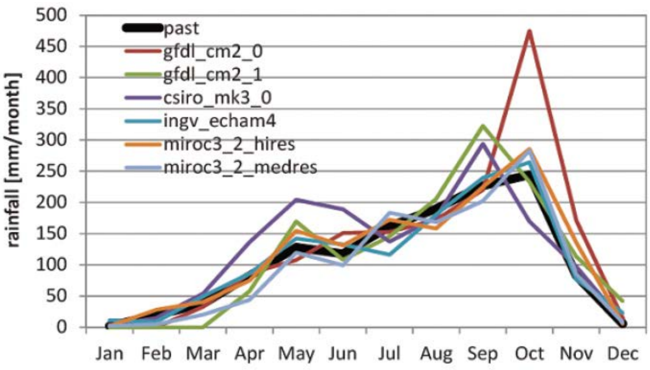

Figure 2. Bias-corrected future precipitation from selected GCM models (coloured lines) and past observed precipitation (Battambang station).

The analysis of planting at optimal times and assuming sufficient irrigation indicated that more than 3 t/ha may be produced (Figure 3). However, without irrigation there is a large yield variation, while with irrigation even planting at the worst times sometimes achieves yields as high as rainfed paddies planted at optimal dates.

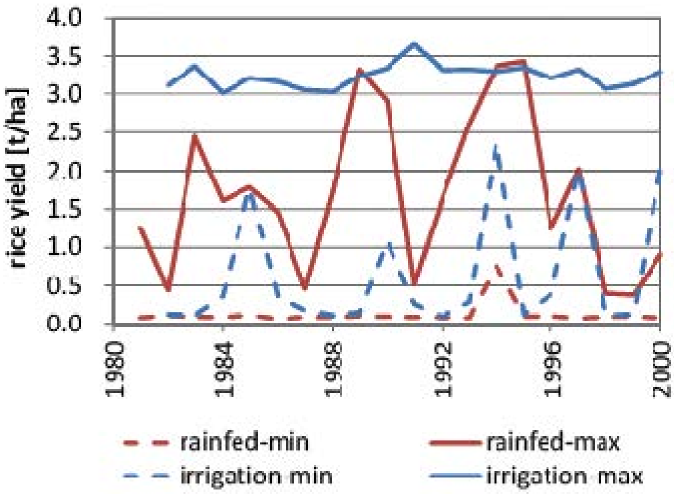

Figure 3. Expected rice yield for rainfed and irrigated paddies. Minimum and maximum yields vary with planting date.

Conclusion

The presented study investigated possible impacts of climate change on rice production in western Cambodia by using the CMIP3 GCM output to force the coupled Hydro-Crop model – a modelling system containing an advanced WEB-DHM hydrological model and SIMRIW-rainfed rice growth model. The use of satellite data was essential for the study, which was carried out by the SAFE project as a part of the Cambodia Water-Climate-Agriculture workbench establishment under the AWCI framework. The results demonstrated the potential of such a system to provide usable information for farmers. Assessment of the rainfall pattern change under future climate conditions showed increased variability of rainfall, i.e. more extreme events (heavy rainfall vs. insufficient rainfall), however results are different among the used GCM outputs. Subsequent analysis of future crop yield depending on planting time did not provide clearly conclusive results but indicated that double crops could be planted and the yield maximised if irrigation water is available at the beginning of the monsoon season. It must be recalled that the present results are based on GCM rainfall simulation capabilities, on which the reliability of the crop model depends.

This study used only a prototype that provides information on past and future rice production, with consideration of climate change. However, there are many uncertainties in CMIP3 GCM precipitation amounts, the bias correction method for obtaining future climate conditions, the algorithms estimating soil moisture from satellite, and the Hydro-Crop model. Their accuracies must be improved prior to becoming operational. For operational use in Cambodia, the Food and Agriculture Organization (FAO) standardised soil type and land use data will be used. More reliable rainfall and soil moisture, elevation at higher resolution, LAI/NDVI, flooded area/depth/duration, paddy field water depth, planting and harvest dates, are also needed. It is desirable to make these data accessible to the public, which is the next step.

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PROJECT INFORMATION

Title:	GEOSS/Asian Water Cycle Initiative/Water Cycle Integrator (GEOSS/AWCI/WCI)
Duration:	Two-year project
Total Funding:	US$ 80,750
Project Leader:	Ms. Shizu Yabe
Full address:	2-1-1, Sengen, Tsukuba, Ibaraki, 305-8505 Japan
Tel:	+81 50 3362 2064
Email:	yabe.shizu@jaxa.jp
Website:	http://www.jaxa.jp/index_e.html