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Rice Terrace Farming Systems
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Surface and Groundwater Flow Response to Climatic Change in the Ifugao Rice Terraces

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Rice Terrace Farming Systems
This working paper series share findings produced as part of the research activities under the Rice Terrace Systems in Rural Asia, a research project of the United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS). The project aims to address dual challenges of both excessive runoff and water scarcity due to climate change by providing ecosystem based adaptation measures to strengthen resilience of the Hani Rice Terraces and Ifugao Rice Terraces.

To find out more, please visit **unu.edu/research/rice-terrace-farming-systems**

ABSTRACT

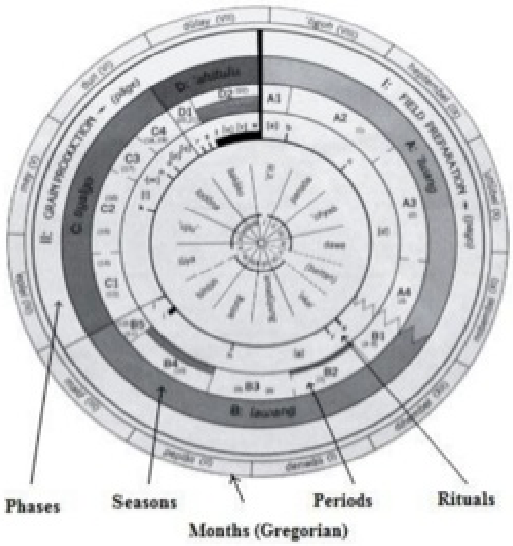
With climate change occurring globally, water resources are also affected. The Ifugao Rice Terraces, composed of mountains of rice paddies constructed and maintained by traditional farming practices, especially stand vulnerable to these changes. It is the aim of this research to assess the effects of climate change to the surface and groundwater hydrology of a system of rice paddies by modelling the hydrologic response of a selected study site in the Ifugao Rice Terraces. Subsequently, adaptation measures are proposed to address the impacts. A site in Kiangan, Ifugao, Philippines was chosen for the study. The catchment properties were characterized using GIS processing. Historical conditions were modelled using observed temperature and precipitation data from 1981-2005. Bias-corrected climate change projections from the Global Climate Model of Japan's Meteorological Research Institute (MRI) were used to model the conditions for 2041-2050 and 2091-2100. The Similar Hydrologic Element Response (SHER) model was used in quantifying the hydrologic fluxes. Results show that the wet seasons of 2041-2050 pose high risks of excess runoff, while the dry seasons of 2091-2100 exhibit the highest risk of water deficits. Interventions were suggested to address these trends.

INTRODUCTION

Global climate change will disrupt the ways that people live and interact with their environment, and peoples' responses to the climate change may have adverse effects on food security (Robert and Robert, 1994; Martin et al., 1999; Pedro, 2000; IPCC, 2007). As an important rice cultivation system adapting to mountainous areas, rice terraces are practiced widely in the Monsoon Asia (Collins and Neal, 1998; McDonald et al., 2006). It can decrease the number of natural disasters because their multifunctions (Liu et al., 2004). However, rice terraces are very much dependent on complex water management and vulnerable to climate change (Takeuchi, 2002; Iiyama et al., 2005; Renting, et al., 2009).

The Ifugao Rice Terraces in Philippines is one of the two (the other being Hani Rice Terraces in China) world-renowned terraced paddy fields with a long history, which have been listed in GIAHS for their wonderful landscape, farming systems and rich functions (Adachi, 2007; Gonzalez, 2000). However, climate change has a big impact on ecosystem and is diminishing the coping capacity of those descended ecological maintenance systems in Ifugao terraces. This brings in a new dimension of changes that may not be able to be coped with by current systems in which more disasters are occurring (Rosamond et al., 2006; Jiao, 2007). Furthermore, the intricate traditional rituals and agricultural practices of the Ifugaos, reflected in the agricultural calendar shown in Figure 1, must adapt to the shifting climatological norms. As the Intergovernmental Panel for Climate Change (IPCC) notes, mountain communities must implement water management strategies which do not assume that known trends will continue.

Figure 1: Ifugao's Agricultural Calendar (Conklin, 1980)



Simulations by PAGASA (Philippine Atmospheric, Geophysical, and Astronomical Services Administration) predict a 1.8 to 2.2°C temperature rise in all parts of the country by 2050. While this may seem trivial, it only takes a little change to cause severe disturbances. Globally, this can lead to an increase in extreme climate-related events, a greater frequency of prolonged droughts, and intense rains and flooding. Among the wonders of the Philippines, and of the world, the Ifugao Rice Terraces (IRT) especially stands vulnerable from the effects of climate change. Changes in hydrologic patterns translate to changes in the farming system to adapt and survive. Thus this study aims to assess the hydrological response of the selected study site in the Ifugao Rice Terraces to climate change. Subsequently, potential adaptation measures are identified to address the impacts.

STUDY SITE AND METHODOLOGY

Based on a field visit on terrace clusters in Ifugao, a study site in Bayninan, Kiangan was chosen as a pilot site. It has an area of 344,339.17 m^2 with an elevation ranging from 785 m to 1,146 m above mean sea level. A terraced paddy and a river were selected for the installation of instruments. Waypoints were marked with a GPS. The selected paddy and river correspond well with the delineated watershed. Figure 2 shows the delineated boundaries of the selected site.

Figure 2a: Study Site in Bayninan, Kiangan: Google Earth ® image with catchment boundary overlay

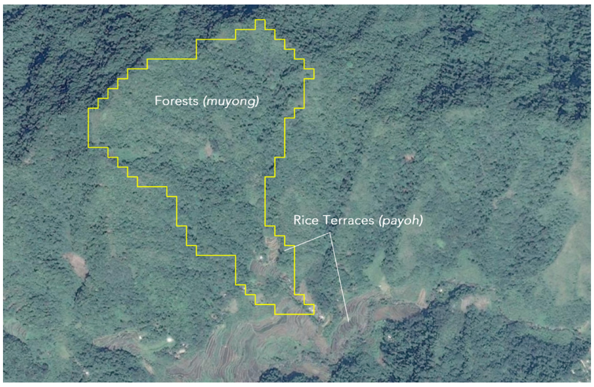
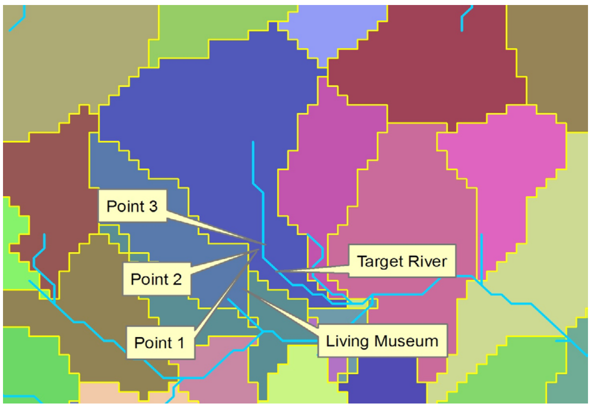
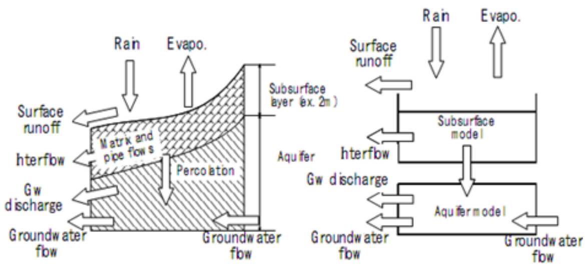


Figure 2b: Study Site in Bayninan, Kiangan: GIS delineation with GPS waypoints marked



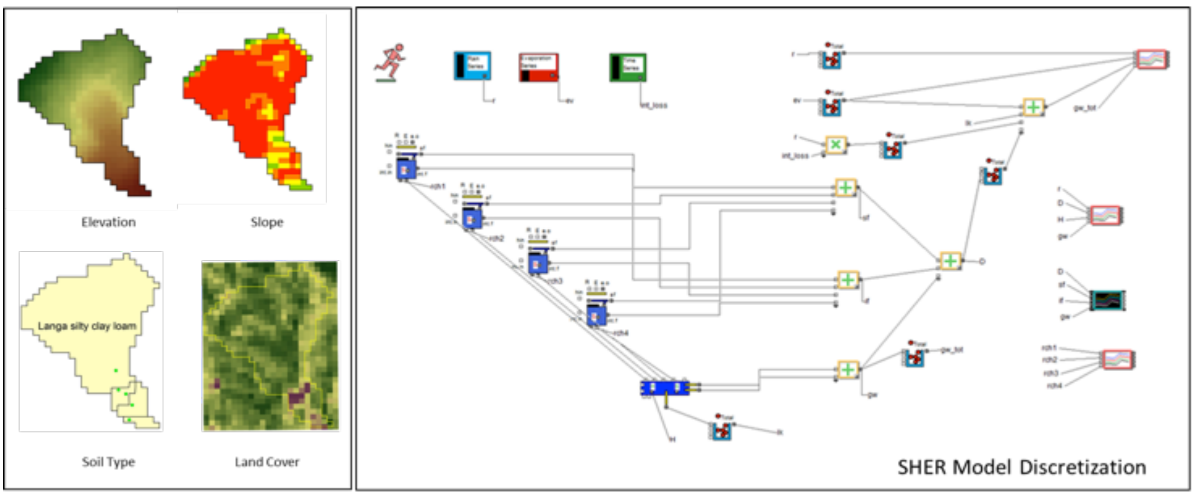
This study simulated scenarios incorporating the effects of climatic change on the groundwater and surface water flow in the cascade of rice paddies using the Similar Hydrologic Element Response (SHER) model (Herath et al., 1992). It is a simplified, physically based hydrological model, which was initially developed to assess hydrological cycle changes due to urbanization, but has been successful applied to several mountainous basins in recent years (Nippon Koei co., 2011). The hydrologic processes incorporated into the SHER model are shown in Figure 3. The model has components of surface flow, subsurface flow, and groundwater (aquifer) flow.

Figure 3: SHER Model Hydrologic Processes (Herath et al., 1992)



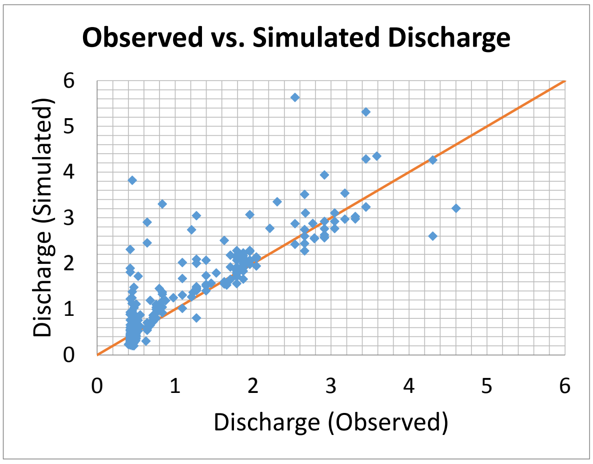
To commence the simulations, the GIS-delineated study area was further discretized into SHER blocks, which are idealized as homogeneous hydrologic response units, based on characteristics of topography, slope, soil type, and land cover. Catchments can be sub-divided into several blocks in order to accurately represent spatial variation. These layers and the corresponding SHER blocks are shown in Figure 4.

Figure 4: SHER Model Domain



Continuous long term observations for the study area are not available, but observations have begun in 2014. As stated in Working Paper No. 3, an automated rain gauge was installed on-site. In addition, a flume for measuring discharge was installed on the target river. These 2014 observed data were used to calibrate the model parameters. Figure 5 shows the comparison of observed vs. simulated discharge. The Nash-Sutcliffe efficiency, a standard measure of the performance of model calibration, was calculated to be 0.6354.

Figure 5: Observed vs. simulated discharge for 2014 data



Historical data from the Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation of the Water Resources (APHRODITE) database were used to establish a baseline scenario. A total of eight future scenarios were described in detail in Working Paper No. 3. In this Working Paper, only the four scenarios based on the Meteorological Research Institute's Global Climate Model (MRI-GCM) were used to assess the impact of climate change on the hydrologic response. This is because, as discussed in WP3, the MRI results were more consistent with the outcomes of the IPCC's WG1 in the Fifth Assessment Report. The MRI-GCM projections were bias-corrected using the quantile-quantile mapping method. Representative Concentration Pathways RCP 4.5 and RCP 8.5 were analysed.

RESULTS AND DISCUSSION

Figure 6 shows the historical water balance in the study area. Peak rainfall occurs in August, and it coincides with the peak in streamflow. Meanwhile, the groundwater head is shown to initially decrease as crops take water from the aquifer for consumptive uses in the low availability of rainfall. The aquifer starts to recharge at the onset of the rainy season, with peak groundwater levels between September and October, and then beginning to decline once again.

Figure 6: Historical water balance

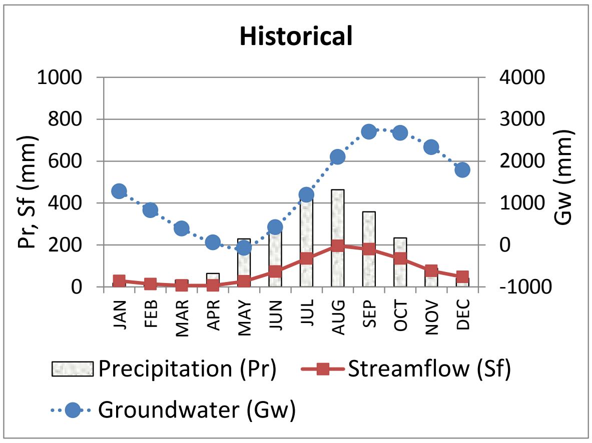


Figure 7 and 8 show the projected hydrologic balance considering future climate change. Among the eight scenarios considered, the highest precipitation was computed for the month of August in the 2091-2100 time slice under RCP 8.5. The highest streamflow stage and groundwater head was computed for September in 2041-2050 under RCP 8.5. There is a high risk of excess runoff during these periods, which could trigger slope instability during these months. To address this, the spillways in the paddies must be expanded to allow the release of excess runoff and avoid the collapse of the terrace walls. Also, these months present an opportunity to store excess water for use during the dry months.

On the other hand, the lowest precipitation was projected for February in the 2091-2100 time slice under RCP 8.5; the lowest streamflow was computed for April in the 2091-2100 time slice (RCP 4.5); and the lowest groundwater head for May in the 2091-2100 time slice (RCP 8.5). These projections indicate that there is a significant overall drying trend for the dry season months at the end of the century.

Further analysis of the projections indicates that only 70-80% of the current evapotranspiration requirements can be met in 2041-2050. For 2091-2100, only 60-70% of the current evapotranspiration requirements can be supplied. This implies a need to make adjustments in the agricultural practices, possibly in terms of shifting the agricultural calendar or changing the type of crops.

A small farm reservoir (SFR) may be constructed in the area to help augment the water supply towards the crop water requirements. The crops in this season are on the initial growing stage and needs enough water for support the growth. The SFR (BSWM 2003) is a small earth dam structure which should collect rainfall and runoff and release this water to supplement water supply. However, if an SFR is to be constructed, further investigation must be done as to its effect to the overall hydrology of the area.

Figure 7: Projected water balance for 2041-2050

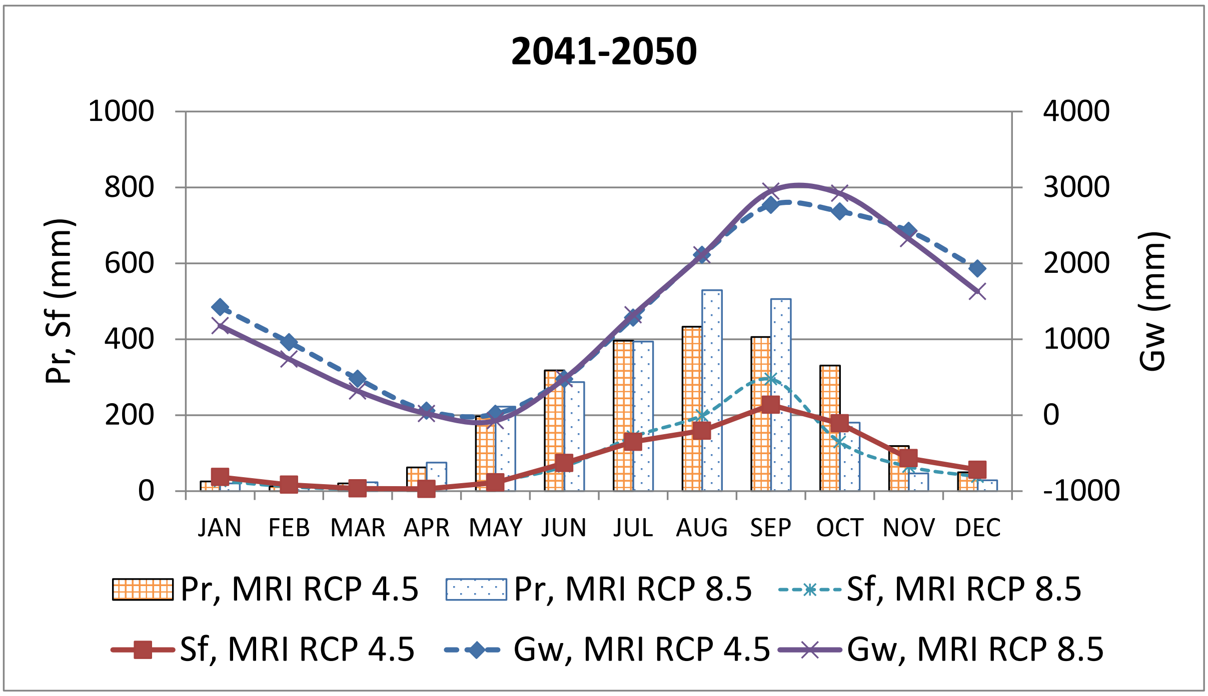
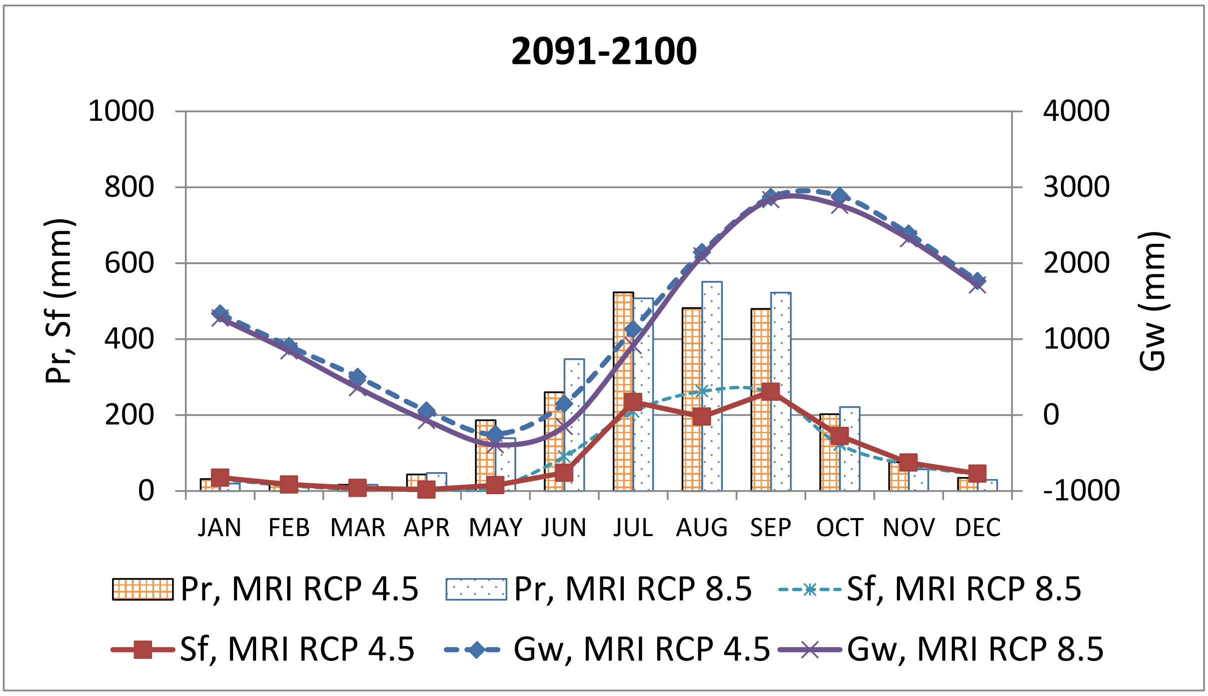


Figure 8: Projected water balance for 2091-2100



SUMMARY

A pilot study site has been selected in Bayninan, Kiangan. An Automated Rain Gauge (ARG) has been successfully installed, and is currently collecting rainfall and pressure data. A flume for measuring streamflow has also been installed on the catchment's outlet. The Similar Hydrologic Element Response (SHER) model was used for the simulations of hydrologic response under historical and future conditions. Projections for future climate used in this paper were obtained from bias-corrected outputs of the MRI-GCM. Finer resolution dynamically downscaled GCM's may provide more information on the effect of climate change in the Ifugao Rice Terraces, especially considering the rugged topography in the study area.

Of the simulations done, results show that the wet seasons of 2041-2050 pose high risk of excess runoff and slope instability. Appropriate measures such as improvements in the drainage system must be implemented to address these risks. Meanwhile, the simulations also show that the dry seasons at the end of the century (2091-2100) are at high risk of water deficits, particularly in the months of April, May, and June. Measures to store excess water during the wet season for use in the dry months must be considered, along with potential changes in the agricultural calendar.

ACKNOWLEDGEMENTS

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