気候変動と土地利用の変化が地域レベルの河川流に与える影響の考察
：スレポック川流域でのケーススタディ

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Considering the impact of climate and land cover change on a local hydrological flow: The case study of Srepok River Basin in Viet Nam and Cambodia

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Abstract: 本研究では、ベトナム中央高地に源流を発し、カンボジア北西部を通り、メコン川へ注ぎ込まれるスレポック川流域において、これからの気候変動と土地利用の変化が地域レベルでの河川流の変動に与える影響を分析するための手法を検討した。IPCC の気候シナリオにもとづく複数の大循環モデル（GCMs）と簡易的な土地利用モデルを用いて、当該流域の将来的な河川流の変動をシミュレートすることで、気候変動および土地利用の変化に対する地域レベルでの適応策を検討することが本研究の最終目的である。しかし、大循環モデルの降雨予測データを地域レベルで利用する上で欠かせないダウンスケーリング手法を十分に組み込むことが出来ていないため、解析手法のさらなる検討が必要である。本報はその手法の検討も含めた試行的なケーススタディとして位置づけられる。

Keywords: **気候変動** (climate change), Arc Hydro
水文解析 (hydrological simulation), HEC-HMS
大循環モデル（global circulation model）

1. Introduction

In the 21 century, water is proving to be at the heart of serious environmental, political and economic issues around the globe. The impact of climate change on the quantity, variability, and spatial distribution of water resources is increasingly cited as a possible hindrance to economic and social development in underdeveloped countries. This is exacerbated by the fact that many of the large river basins of the world are shared among several nations (Rogers, 1993: Heather *et at.*, 2000).

The IPCC (2007) has promoted “adaptation” as the best means for responding to climate change. To study water resource adaptation, attention to local scale is essential because the structure of the solution is different for each scale and set of local characteristics. Concrete adaptations based on practical analysis are often lacking, particularly on local and regional scales.

As yet, a reliable framework and tools needed to support climate adaptation in river basins remain unavailable. However, recent developments in modeling and data acquisition and processing have made integrated approaches to sustainable water resource management more feasible.

The purpose of this study is to investigate the potential impact of climate and land-cover changes on local stream flow in the next several decades. The level of uncertainty in predicting the outcome of hydrological simulations using existing methods and data will be discussed. Suitable adaptations for a given area will be proposed in light of these uncertainties, and the options of local decision makers and stakeholders will be explored.

Vorosmarty *et al.* (2000) and Oki and Kanae (2006) reported the contributions of climate change, human development and their combination to the future state of global water resources. The IPCC’s regional analysis indicates freshwater availability in South-East Asia, particularly in large river basins, is projected to decrease by the 2050s (Cruz *et al.*, 2007). Recently, the impacts of climate change on future hydrology were investigated

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in the entire large river basin level such as the Nile and the Mekong River basin (Beyene *et al.*, unpublished; Kiem *et al.*, 2008).

A multi scale adaptation strategy is necessary for assessing the hydrological impacts of climate change on transboundary river such as the Mekong. Adaptation involves a variety of factors at different spatial scales from individual villages to the entire basin, including the following types of activities: investment planning for new or expanded infrastructure (reservoirs, irrigation systems, levees); operation and regulation of existing systems (accommodating new uses or conditions); maintenance and major rehabilitation of existing systems (e.g. dam safety, levees, etc.); modifications in processes and demands (water conservation, pricing, regulation, legal); and introduction of new efficient technologies (desalting, biotechnology, drip irrigation, reuse, recycling, solar, etc.).

World Bank (2004) suggests the necessary of sector-specific adaptation. For example, planed water management interventions could marginally decrease wet season flows and substantially increase dry season flows in rivers like the Mekong where wet season river flows are estimated to increase and the dry season flows projected to decrease. Developing analysis process of the climate and land-cover impact on local stream flow level should not only contribute to decision support for a given area, but also in many locations with different situations. We plan to develop such an approach using the IPCC and other hydrological scenarios. The significance of this project is developing a systematic approach for integrating a wide range of data models, data formats, and research methodologies into common GIS computing environments for conducting hydrological simulations in local level.

2. Study area and data

2-1 Study area

The Mekong River is the largest international river in Asia, which rises in the Tibetan Plateau and empties into the South China Sea after travelling 4,000 km and flowing through six countries: China, Myanmar, Thailand, Lao PDR, Cambodia and Vietnam. Srepok River Basin, the main tributary of the Lower Mekong, was selected as a study area (Figure 1). The total length of Srepok River is 315km and the catchment area is 30,100km^2. Population growth and agricultural-land expansion, especially in upstream of Viet Nam side, are of increasing concern (Carl Bro Group, 2005). To realize a fair water use in both upstream and downstream, exploitation and the use of water resources in the basin should be taken into consideration for the benefit of the whole region.

The Hyetograph at Ban Don, Viet Nam is shown in Figure 2. Rainy season begins in May and ends in October in the upper Srepok River basin. Dry season is from December to March. The stream flow in dry season in the upper Srepok River basin is less than 30% of annual flow (Ty, 2008). Basic meteorology data in Srepok River basin is shown as follows (Carl Bro Group, 2005): The average annual temperature: 23°C; annual

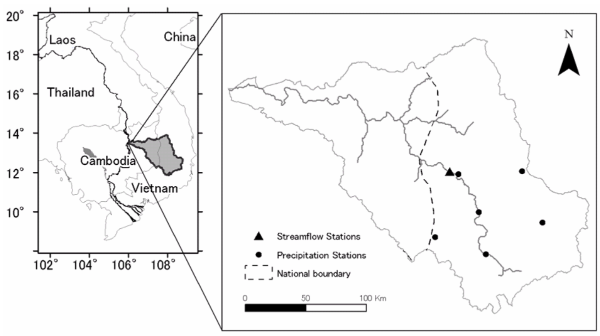

Fig. 1 Location of the Srepok River basin and the hydro-meteorological stations

Table 1 Contemporary data list

Theme	File name	Year	Data type, Scale	Data Source
Land Cover	Forest and Land Cover Types	1997	Polygon, 1:50,000	Mekong River Commission
Soil	Soil Map of the Lower Mekong Basin	2002	Polygon, *1:50,000 (Viet Nam)* *1:100,000 (Cambodia)*	Mekong River Commission
Terrain	Digital Terrain Model (DTM) for the Lower Mekong Basin	2005	Raster data, 50 m resolution	Mekong River Commission
Population	Gridded Population of the World: Future Estimates	2000	Raster data, 2.5 arc-minutes resolution	CIESIN, Columbia University (2008)
Precipitation	Monthly (daily) precipitation	1978-2006	Table, 4 locations	Hydro-Meteorological Data Center (HyMetData), Viet Nam
Stream flow	Monthly (daily) stream flow	1978-2006	Table, 1 location	Hydro-Meteorological Data Center (HyMetData), Viet Nam

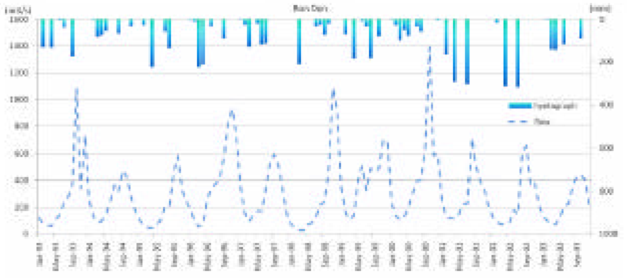

Fig. 2 Mean monthly precipitation and stream flow at Ban Don, Viet Nam (1993-2003)

humidity: 78-83%; annual evaporation: 1,300 mm; and average rainfall: 1750 mm.

2-2 Data

Contemporary GIS data such as land-cover, soil, and digital elevation models was obtained from the Mekong River Commission Secretariat, Lao PDR. Four locations (Ban Don, Duc Xuyen, Cau 14, Krongbuk) of monthly and daily precipitation table data and one location (Ban Don) of monthly and daily stream flow data were obtained by the Hydro-Meteorological Data Center (HyMetData), Viet Nam. A detail of these data is shown in Table 1.

3. Methodology: Model and implementation

3-1. Models

3-1.1 General Circulation Models (GCMs)

The 23 AOGCMs (Atmosphere-Ocean General Circulation Model) were widely used in the IPCC Fourth Assessment Report (AR4), Three GCMs with relatively high spatial resolution were selected as input data for hydrologic simulation in this study (Table 2). Among six global greenhouse gas emissions scenarios used for AR4, scenarios A2 and B1 were selected for the use of this study because they are the most widely simulated scenarios in all models. The A2 scenario describes a very heterogeneous world, underlying theme of self-reliance and preservation of local identities with continuously increasing global population and regionally oriented economic development. Per capita economic growth and technological change are more fragmented and slower than in other scenarios. The A2 scenario projects global average Carbon Dioxide concentrations will reach 850 ppm by 2100. B1 scenario, on the other hand, describes a convergent world with the same global population that peaks in midcentury and decreases afterward, but with rapid changes in economic structures with deductions in material intensity, and the introduction of clean and resource-efficient technology. The B2 scenario projects

Table 2 Description of the selected GCMs

Model ID, Vintage	Modeling Group, Country	Atmosphere Resolution, References
CCSM3, 2005	National Center for Atmospheric Research (NCAR), USA	T85 (1.4° x 1.4°) L26 Collins *et al.* , 2004
CSIRO -MK3.0, 2001	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia	T63 (~1.9° x 1.9°) L18 Gordon *et al.* , 2002
MIROC3.2 (hires), 2004	Center for Climate System Research (UT), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	T106 (~1.1° x 1.1°) L56 K-1 Developers, 2004

Carbon Dioxide concentrations reach 550 ppm by 2100 (IPCC, 2000).

3-1.2 Arc Hydro data model

The Arc Hydro Data Model can be defined as a geographic database containing a GIS representation of a Hydrological Information System (Maidment, 2002). This data model was used to develop the sub-basin geodatabase (Zeiler, 1999) in the Srepok River basin. The reason for choosing the Arc Hydro data model and tools is that this data model allows us to represent the water flow in study area and connect to hydrological simulation software easily. This is freely downloadable from the ESRI Website.

3-1.3 HEC-Hydrologic Modeling System (HMS)

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems (US Army Corps of Engineers, 2008). This program was used for hydrological simulations in this study. A GIS companion product, called HEC-GeoHMS, was used to build basin and meteorological models in the ArcGIS environment for use with the HEC-HMS program (US Army Corps of Engineers, 2008). This software is freely downloadable from the HEC-HMS Website.

3-1.4 Land-cover changing model

The process for preparing future land-cover model in a simple manner was developed in this study. The process is described as follows. 1). Using gridded global population data from Columbia University's Website (CIESIN, 2008), per annum growth rate of 1.95% (Carl Bro Group, 2005) was applied uniformly to whole area to predict populations for 2025 and 2050. 2) Gridded population for 2000 was compared with land-cover 1997 to find threshold values for each landuse categories. This threshold values were used to reclassify and convert the raster to feature dataset and two new feature classes of future land-cover was generated. 3). In future land-cover layer, new fields [S1: As same as 1997; S2: Urban area expansion; S3: Agriculture expansion, S4: Maximum development (S2+S3), etc...] were calculated for landuse in different years/scenarios using VBA code used for field calculator. 4). Finally four types of land-cover data were generalized for each year in 2025 and 2050. The change of land-cover categories was supposed to affect the Curve Numbers (McCuen, 1982; SCS, 1986) in each watershed.

3-2. Approach

3-2.1 Analysis flow

A series of analysis flow is shown in Figure 3. First contemporary rainfall, stream flow and land-cover data were converted into ArcGIS environment to build a sub-basin geodatabase using Arc Hydro data model and tools. Second HEC-GeoHMS was used to set up parameters and methodologies for HEC-HMS simulation and convert the GIS data (geodatabase format) into HEC-HMS file format. Third, contemporary rainfall - outflow process was simulated and calibrated using HEC-HMS hydrologic simulation program in order to obtain hydrological parameters in the study area. Then, future rainfall, namely the output of GCMs based on the IPCC climate scenario in 3-1.1, and future land-cover, calculated from a simple model based on population increase in 3-1.4, were used as input data for future rainfall-outflow process.

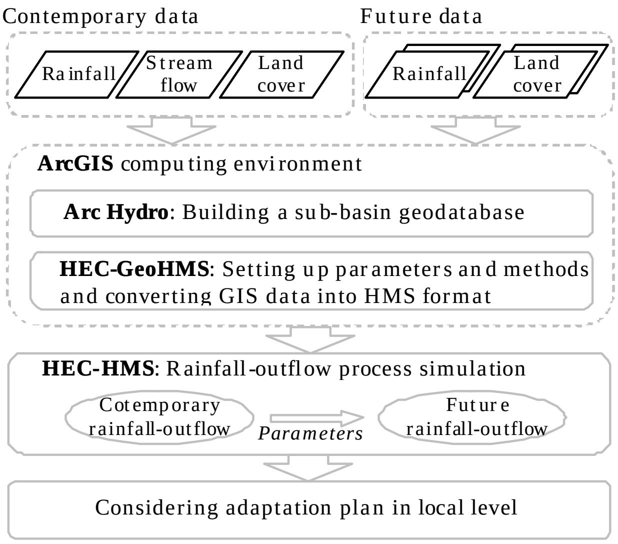

Fig. 3 Analysis flow

3-2.2 Analysis framework

Table 3 shows the entire simulation framework. Finally five climate models produced by the IPCC climate scenarios with three GCMs were used, because the MIROC model of A2 scenario was not yet opened. The land-cover change models developed in this study was shown in the table as well. Hydrological simulations were conducted in the circled combination in order to investigate the interrelationships between climate and land-cover change. The results of simulations around 2025 are represented in following chapter.

Table 3 Analysis framework

			IPCC SRES Scenario A2			IPCC SRES Scenario B1		
			CCSM	CSIRO	MIROC	CCSM	CSIRO	MIROC
Land Cover	1997	-	-	-	-	-	-	-
	2025	S1	-	-	-	○	○	○
		S2	○	○	-	-	-	-
		S3	-	-	-	○	○	○
		S4	○	○	-	-	-	-
	2050	S1	-	-	-	○	○	○
		S2	○	○	-	-	-	-
		S3	-	-	-	○	○	○
		S4	○	○	-	-	-	-

4. Proto-typed simulation during 2023-2028

Despite continuing improvement in their physical representations of the climate system, there remains a substantial scale mismatch between the GCMs and most hydrologic models (Kundzewicz *et al.*, 2007). In general, a spatial downscaling method has been used in climate change studies (Beyene et al., unpublished; Kiem et al., 2008), because the atmosphere resolutions of the GCM's output are from 1.1 degrees (i.e., future rainfall grid size is more than 100 km). However, we had a difficulty to find suitable method for downscaling precipitation data around the Mekong, though various downscaled future climate data is available in the US and Europe. Therefore followings are just as a result of trial simulation, because the original GCMs output without downscaling were used as input data for simulations.

Figure 4 shows a sample hydrograph of proto-typed simulation for comparing two IPCC scenarios from 2023 to 2028 in Ban Don, Viet Nam. Dashed line is the stream-flow using the IPCC B1 scenario with CCSM3-GCM produced by NCAR, USA. Straight line is the stream-flow using A2 scenario with the same GCM output. Around this period, both stream flows have similar tendency. Hydrological simulations beyond 2050 have to be investigated as well, because major difference of CO_2 concentrations between A2 and B1 scenarios appear after around mid-century to 2100 (IPCC, 2007).

The hydrograph of Figure 5 shows comparison between two land-cover scenarios using the same GCM output with the same IPCC scenario: CSIRO-MK3 with the B1 scenario. Straight line is the stream-flow of the land-cover scenario-1 assumed as same as the land-cover in 1997. Dashed line is the stream-flow of land-cover scenario-3, assumed maximum expansion of agricultural area, using the same GCM output. The difference among several land-cover scenarios was small. Though the sufficient consideration is not achieved, reexamination of the land-cover model might be required.

The hydrograph of figure 6 shows the difference of the hydrological simulation among three different GCMs. Dotted line is the simulated stream flow using CCSM3. Straight line is the stream flow using MIROC model. Dashed line is the simulated stream flow using CSIRO model. There are big differences among GCMs. Further consideration of model uncertainties is required to cope with these differences.

5. Summary

Proto-typed hydrological simula -tions were conducted by integrating a wide range of data models, data formats and research methodologies into common GIS computing environments, except incorporating a spatial downscaling method. Modifying analysis process using a suitable downscaling technique in the Mekong is required for solving the problem in the use of GCM outputs with the mismatch of spatial grid scales between GCMs and hydrological processes. Further investigation is necessary for developing a method for clarifying the impact of both climate and land-cover change by analyzing the various range of simulation results including some extent of uncertainties.

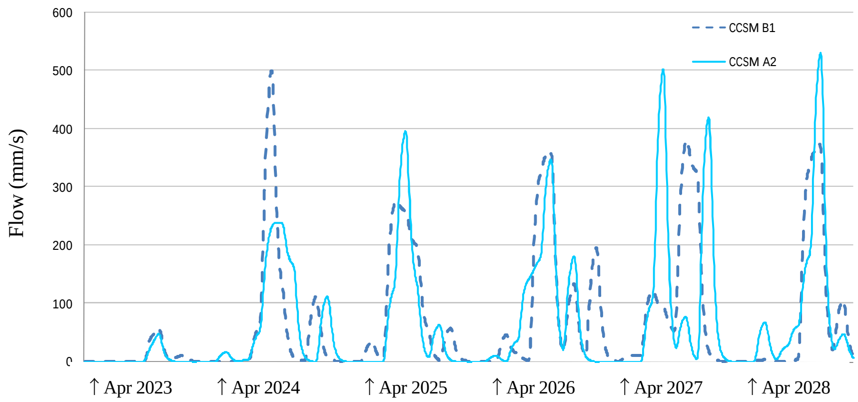

Fig. 4 Hydrograph of the two IPCC scenarios using same GCM output (Apr. 2023 – Oct. 2028)

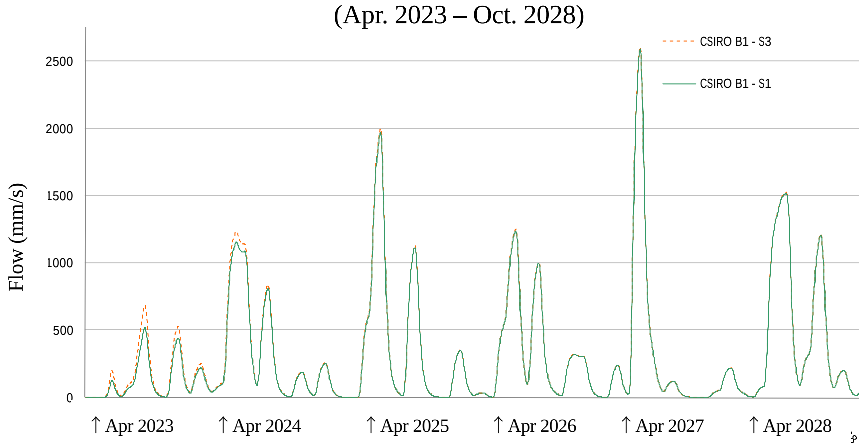

Fig. 5 Hydrograph of the two land-cover scenarios using same IPCC scenario of GCM output (Apr. 2023 – Oct. 2028)

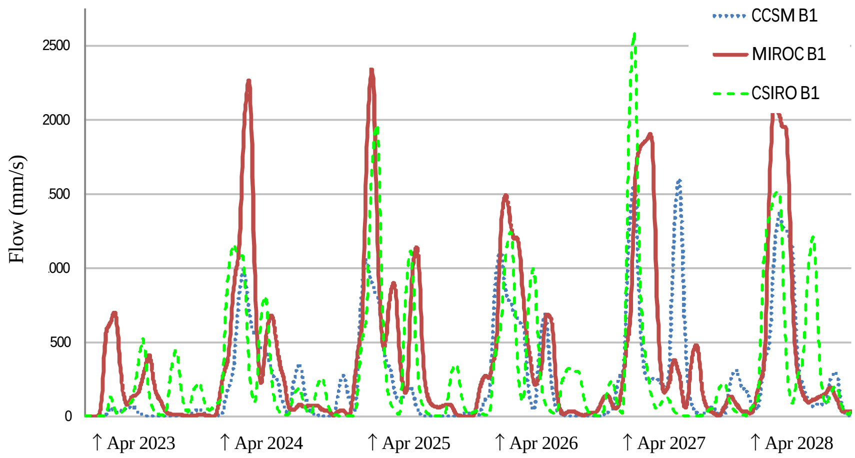

Fig. 6 Hydrograph of three GCMs output using same IPCC and land-cover scenario (Apr. 2023 – Oct. 2028)

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