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Assessing hydrologic changes across the Lower Mekong Basin

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ABSTRACT

Study region: In this study, 33 catchments across the Lower Mekong Basin in Southeast Asia are examined to detect historical changes in their hydrological response via a model-based methodology.

Study focus: Intensive development over the past half century across Southeast Asia's Lower Mekong Basin has inevitably affected natural resources. Large areas have been converted from forests for subsistence and commercial agriculture, and urban development. We implement an innovative approach to screen hydrologic data for detecting impacts of such large-scale changes on hydrological response. In a first step, temporal changes in the rainfall-runoff relationship were assessed using the parsimonious, two-parameter GR2M hydrological model. In a second step, a distribution-free statistical test was applied to detect whether significant changes have occurred in the wet season (high flow) and dry season (low flow) conditions.

New hydrological insights for the region: Our results indicate that the majority of catchments (64% of those considered) with sufficiently long data records exhibited no discernable trends in hydrological response. Those catchments that did exhibit significant trends in hydrological response were fairly evenly split between increasing trends (between 21% and 24%) and decreasing trends (between 15% and 12%) with time. There was a lack of evidence that these changes where brought about by shifts in precipitation or potential evapotranspiration; however, catchments exhibiting significant increasing trends in hydrological behavior were found to have different land cover compositions (lower percentage of forest coverage and subsequently higher paddy rice coverage) than those exhibiting significant decreasing trends. The approach presented here provides a potentially valuable screening method to highlight regions for further investigation of improved mechanistic understanding. Without this connection, we might be blind to future hydrological shifts that can have significant impact on development.

1. Introduction

Surging economic growth in developing countries is often accompanied by the expansion of agriculture and infrastructure. Such expansion typically has both direct and indirect impacts on natural resources (Scanlon et al., 2007). For example, it is often seen that changes in land cover and land-use affect water yields (i.e. runoff, including groundwater outflow, and storage) within a catchment. This is typically due to the role land cover plays in the water cycling including evapotranspiration (e.g., Jaramillo et al., 2013) and

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recharge (e.g., Tessema et al., 2014) processes. Both groundwater recharge and streamflow generation in a basin are subject to change, especially when alteration of vegetation or agricultural expansion occurs over large areas, respective to the catchment size (Brown et al., 2005; Bruijnzeel, 2004; Andreassian et al., 2003). The magnitude and seasonality of hydrological impacts are, however, highly variable depending on regional conditions. As such, there is still clear need for studies that investigate techniques able to distill change in hydrological behavior and its potential relationship with land cover at regional scales – especially for regions targeted for development through exploitation of natural resources (e.g. Lyon et al., 2014).

Nowhere is this need more obvious than in southeast Asia where economic growth and increased land and water resource pressure have been substantial over the past half century. As the region's economies have soared, many natural resource stocks have declined. Across the Lower Mekong Basin (LMB), covering portions of Laos, Thailand, Cambodia and Vietnam, deforestation has been considerable ranging from land-clearing for strategic purposes during the Vietnam War (Lacombe et al., 2010; Lacombe and Pierret, 2013) to economic and population growth driving the logging and agriculture expansion for self-subsistence and markets. During the 1970s and 1980s, the region served as the principal source of timber for the trade of tropical hardwood internationally (Douglas, 1999). Deforestation rates have increased dramatically since the late 1980s, bringing the region's forest destruction rate on par with tropical Africa and tropical America (Bernard and De Koninck, 1996). Between 1990 and 2005, Thailand lost 1.5 million hectares of forest, while Laos and Cambodia lost 1–2.5 million hectares each year, resulting in the highest rates of deforestation in the region (MRC, 2010). However, this trend appears to have reversed in recent decades: according to the most recent Global Forest Resources Assessment (FAO, 2015), Laos and Vietnam are listed among the 13 countries globally which were likely to have passed through a national forest transition between 1990 and 2015, with a switch from net forest loss to net forest expansion.

While forest cover change has occurred over the past 50 years, agricultural irrigation and expansion has increased under growing populations. In 2000, irrigated area in southeast Asia reached 18 million ha, 80% of which was for rice cultivation extending traditional rainfed ventures. Large-scale irrigation systems now make up about 40% of the LMB area (FAO, 2007). Coupled to irrigation and agricultural expansion, construction of infrastructure such as roads and urban areas also took place during this time (Ziegler et al., 2004). These widespread activities have likely had an effect on the hydrological behavior (i.e. runoff response) of streams and rivers in the region through the reallocation and rerouting of existing terrestrial flows (i.e. internal catchment drainage). These and other influences on the hydrological behavior in the area have important social implications, as most of the region's population of 60 million relies closely on natural resources for survival. This is most concerning during the dry season as irrigation from agriculture tends to reduce flows whereby the current expanding demand could result in detrimental water shortages across the region (FAO, 2007). In addition to drought, large increases in runoff after rain events can lead to damaging floods, erosion, and downstream siltation, impacting local livelihoods.

Several simulation studies in the LMB region have been conducted with the intention to link the effects of land cover (and subsequent change) with hydrology using models of various levels of complexity (Kite, 2001; Thanapakpawin et al., 2006; Costa-Cabral et al., 2008; Homdee et al., 2011; Wang et al., 2016). Though some of these forecasts show decreasing resource availability results consistent with the expected relationships outlined above, conclusions are hard to draw due to the complex relationship of vegetation and land-use with hydrology (e.g., van der Velde et al., 2014). Previous research has highlighted the challenges of evaluating the connection between land cover and hydrology due to the complex role of underlying geomorphology (Douglas, 1999; Bruijnzeel, 2004), issues of scale and the roles of climate variability (Bruijnzeel, 2004), counteracting effects of different land-use changes (Bruijnzeel, 1990), and lack of adequate hydro-meteorological and land-use data in the region.

To try and overcome these issues, Lacombe et al. (2016) recently developed a methodology to isolate climatic impacts from other potential changes on water cycling. Specifically, they combined the monthly 2-parameter lumped GR2M model of Mouelhi et al. (2006) to represent hydrology with the distribution-free trend testing method of Andreassian et al. (2003) to identify changes in hydrology at a catchment scale. This approach allows for de-coupling of climatic change impacts from the resultant hydrological estimates. Lacombe et al. (2016) used this methodology to examine two relatively small catchments ($< 1\ km^2$) with contrasting but extensive land cover change in Laos and Vietnam for significant variation in runoff. The study revealed a correlation between afforestation and changes in hydrological behavior; however, the hydrological impacts differed depending on the afforestation strategy and vegetation types with increased and decreased flows in the catchment in Laos and Vietnam, respectively. Although the extent of the study was limited in spatial scale to the two catchments, the results highlight the complexity to be anticipated regionally with regards to the hydrological impact of large-scale shifts in vegetation cover and resource management.

To this end, our study seeks to continue the exploration of the rainfall-runoff response using the modeling framework previously applied to the two catchments in Laos and Vietnam (Lacombe et al., 2016) and expand the analysis across the LMB. We do this using a subset of the large catchments ($> 200\ km^2$) from a study by Lacombe et al. (2014) considering only catchments where there were (1) at least 10 years of data and (2) relatively good GR2M model performance. Specifically, we test for the potential existence of trends (either increasing or decreasing) in the hydrological behavior of these catchments independent from trends that could be attributed to climatic changes. Due to data availability and scale limitations, we cannot explicitly quantify land cover change across all the catchments considered (as was done for the two catchments in Lacombe et al. (2016)); however, the catchments considered are classified static using 2003 land cover composition and geomorphologic catchment characteristics to investigate the possible connection between changes in hydrologic behavior and environmental factors.

2. Site description

The Mekong River Basin ($795,000\ km^2$) is one of the world's largest catchments, spanning over six countries in southeast Asia. With its headwaters in the Tibetan Plateau in China, the Mekong gains volume as it heads southwards through Myanmar, Laos,