Science of the Total Environment 649 (2019) 601–609

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The Mekong's future flows under multiple drivers: How climate change, hydropower developments and irrigation expansions drive hydrological changes

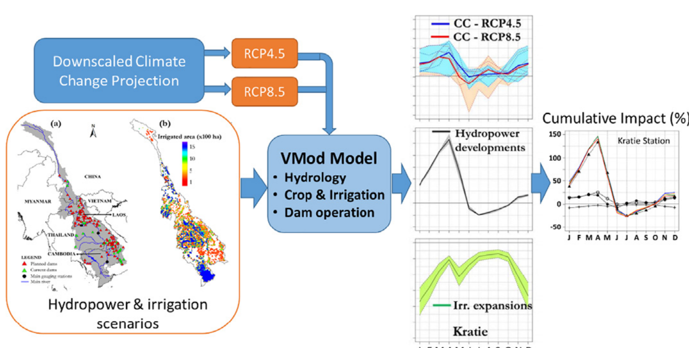
Long P. Hoang [a,*], Michelle T.H. van Vliet [a], Matti Kummu [b], Hannu Lauri [c], Jorma Koponen [c], Iwan Supit [a], Rik Leemans [d], Pavel Kabat [a,e], Fulco Ludwig [a]

[a] *Water Systems and Global Change Group, Wageningen University, P.O. Box 47, 6700 AA Wageningen, the Netherlands*
[b] *Water & Development Research Group, Aalto University, P.O. Box 15200, Aalto, Finland*
[c] *EIA Finland Ltd., Sinimäentie 10B, 02630 Espoo, Finland*
[d] *Environmental Systems Analysis Group, Wageningen University, P.O. Box 47, 6700 AA Wageningen, the Netherlands*
[e] *International Institute for Applied System Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria*

HIGHLIGHTS

- Climate change, hydropower and irrigation developments strongly alter the Mekong's future flows.
- Total annual flows changes (-3% to 15%) are primarily driven by irrigation expansions and climate change.
- Hydropower developments show strongest impacts on seasonal flows: up to +70% (dry season) and -15% (wet season).
- Future flow changes pose serious consequences, requiring strategic development planning and effective adaptation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 1 May 2018
Received in revised form 6 August 2018
Accepted 12 August 2018
Available online 17 August 2018

Editor: R Ludwig

Keywords:
Mekong basin
Climate change
Irrigation expansion
Hydropower dams
Hydrological impacts
VMod model

ABSTRACT

The river flow regime and water resources are highly important for economic growths, flood security, and ecosystem dynamics in the Mekong basin – an important transboundary river basin in South East Asia. The river flow, although remains relatively unregulated, is expected to be increasingly perturbed by climate change and rapidly accelerating socioeconomic developments. Current understanding about hydrological changes under the combined impacts of these drivers, however, remains limited. This study presents projected hydrological changes caused by multiple drivers, namely climate change, large-scale hydropower developments, and irrigated land expansions by 2050s. We found that the future flow regime is highly susceptible to all considered drivers, shown by substantial changes in both annual and seasonal flow distribution. While hydropower developments exhibit limited impacts on annual total flows, climate change and irrigation expansions cause changes of +15% and −3% in annual flows, respectively. However, hydropower developments show the largest seasonal impacts characterized by higher dry season flows (up to +70%) and lower wet season flows (−15%). These strong seasonal impacts tend to outplay those of the other drivers, resulting in the overall hydrological change pattern of strong increases of the dry season flow (up to +160%); flow reduction in the first half of the wet season (up to −25%); and slight flow increase in the second half of the wet season (up to 40%). Furthermore, the cumulative impacts of all drivers cause substantial flow reductions during the early wet season (up to −25% in July), posing

* Corresponding author.
E-mail address: long.hoang@wur.nl (L.P. Hoang).

https://doi.org/10.1016/j.scitotenv.2018.08.160

challenges for crop production and saltwater intrusion in the downstream Mekong Delta. Substantial flow changes and their consequences require careful considerations of future development activities, as well as timely adaptation to future changes.

1. Introduction

The Mekong is the largest and most important transboundary river basin in Southeast Asia. The river starts in the Tibetan Plateau and flows across China, Myanmar, Laos PDR, Thailand, Cambodia, down to its endpoint in the East Sea (also known as South China Sea) in Vietnam. The societies and economies along the river are highly dependent on the commonly shared water resource, especially in the agriculture, fisheries and energy sectors (Hortle, 2007; Grumbine and Xu, 2011; Arias et al., 2014). A large share of the population (currently 70 million, based on Varis et al., 2012) including millions of farmers in Cambodia, Laos PDR, and the Vietnamese Mekong Delta have their livelihoods directly supported by the water resources from the river. Abundant water resources and a strong seasonal flood pulse also create the largest wetland (i.e. Lake Tonle Sap) in Southeast Asia. This wetland system exhibits important ecological values (Arias et al., 2014; Lamberts and Koponen, 2008) and contributes to about 80% of the protein supply for millions of local inhabitants (Hortle, 2007). The Mekong also features high potentials for hydropower production, of which only a small proportion (i.e. about 10%) is currently exploited (MRC, 2010). Hydropower production generated about USD $250 million per year (MRC, 2005) and contribute substantially to regional economic developments. All these great benefits and high dependencies highlight the importance of the Mekong's water for local livelihoods and regional economic developments.

Nevertheless, the Mekong's flow regime and water resources are expected to experience substantial changes due to multiple factors including climate change, hydropower developments and irrigated land expansions. Recent studies including Eastham et al. (2008), Västilä et al. (2010), Lauri et al. (2012) and Hoang et al. (2016) suggest that climate change will likely change the Mekong's flow regime, resulting in higher magnitudes and frequencies of floods and droughts. Seasonal flows are also projected to change under future hydropower developments throughout the basin (Lauri et al., 2012; Piman et al., 2013). Also, rapid irrigated land expansions are projected for the Mekong region, which could result in almost doubling the total irrigated area within the coming two decades (MRC, 2010). Irrigated land expansions will result in increasing irrigation demands and will likely affect the Mekong's flows, especially during the dry season (Piman et al., 2013). Although existing studies provide useful insights about the impacts of individual factors, much less attention was paid to the combined impacts of multiple factors on the Mekong's future flows. For instance, recent studies including Hoanh et al. (2010), Lauri et al. (2012), Piman et al. (2013) and MRC (2018) shifted focus on multiple driver impacts. However, they tend to focus on impact quantification while the underlying mechanisms and impact accumulations are often neglected. Motivated by this knowledge gap, this study focuses on the dynamics and mechanistic understandings of future hydrological changes under multiple driving factors, by comparing the impacts of individual drivers and analyse how they interplay and contribute to the cumulative impacts. Mechanistic understanding of hydrological changes not only advances the current understanding about the Mekong's future flow regime, but also contributes to effective management of the shared water resources in this important transboundary river basin. Additionally, given the potentially large, sometimes contrasting impacts of each factor, understanding future hydrological changes caused by multiple driving factors is highly important to effectively inform and support long-term planning and decision making in the Mekong basin.

Against this background, the main objective of this study is to characterize and quantify the impacts of multiple factors, including (1) climate change, (2) hydropower dam developments and (3) irrigated land expansions on the Mekong's future flow regimes. For such objective, we developed a coupled modelling system including a dams operation module and a crop simulation module into a distributed hydrological model, allowing for simultaneous simulation of the three factors. Furthermore, we prepared multiple scenarios to characterize future changes for each factor by 2050s. Simulation results under these scenarios are presented to provide insights about how river flows at representative locations will change due to the considered driving factors.

2. The Mekong River basin

The Mekong (Fig. 1) is an average-sized river basin compared to other major rivers of the world. The river's total length and total catchment area are 4800 km and 795,000 km^2, respectively. However, the Mekong's total annual discharge volume (i.e. 475 km^3 per year) is much higher than other similarly-sized river basins, making it the 10th largest river in this regard (Dai and Trenberth, 2002). High discharge volume is mainly attributed to the monsoonal activities, most importantly the south-west monsoon (MRC, 2005; Delgado et al., 2012). The tropical monsoonal climate results in two distinctive wet (May–October) and dry seasons (November–April), with over 75% of the total discharge generated during the wet season (MRC, 2009a). During the flood season, large floodplains are flooded annually in the Mekong downstream countries, especially in Cambodia and Vietnam. The annual flood pulse and nutrient-rich floodwater supports high aquatic biodiversity, rich fisheries and a highly productive rice production system (Arias et al., 2012; Arias et al., 2014; Hoang et al., 2018). Extreme floods, however, cause live losses and large damages to crops and infrastructure, constituting a major safety risk in the downstream delta.

Riparian countries along the Mekong, including China, Myanmar, Laos PDR, Thailand, Cambodia and Vietnam, are experiencing rapid socio-economic developments. Population is increasing steadily and this trend is projected to continue in the coming decades (Varis et al., 2012). Irrigated land expansions are increasing throughout different parts of the basin and recent studies also project drastic future increases in irrigated land in the Mekong (Eastham et al., 2008; MRC, 2010). Similarly, energy supply, mostly through hydropower developments is accelerating throughout the basin (Orr et al., 2012; Grumbine and Xu, 2011). These rapid developments will increase Mekong's water resources utilisation and, subsequently modify the river's current flow regime. On top of socio-economic development, climate change is projected to have substantial impacts on river flows (Lauri et al., 2012; Hoang et al., 2016). All in all, flow regime changes caused by climate change and human activities will pose great challenges for socio-economic developments, especially for agriculture, fishery, water resources management and ecosystem dynamics. Therefore, quantifying the Mekong's future flow regime changes and characterizing the underlying mechanisms are especially important.

3. Climate change, irrigation expansion and hydropower development scenarios

3.1. Climate change scenarios

Baseline climate data (1971–2000) were prepared from the WATCH forcing data (Weedon et al., 2011) and the APHRODITE data set (Yatagai