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Future sediment dynamics in the Mekong Delta floodplains: Impacts of hydropower development, climate change and sea level rise

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ABSTRACT

The Mekong Delta is under threat due to human activities that are endangering livelihood of millions of people. Hydropower development, climate change and the combined effects of sea level rise and deltaic subsidence are the main drivers impacting future flow regimes and sedimentation patterns in the Mekong Delta. We develop a sensitivity-based approach to assess the response of the floodplain hydrology and sediment dynamics in the delta to these drivers. A quasi-2D hydrodynamic model of suspended sediment dynamics is used to simulate the sediment transport and sediment deposition in the delta, including Tonle Sap Lake, for a baseline (2000–2010) and a future (2050–2060) period. For each driver we derive a plausible range of future states and discretize it into different levels, resulting in 216 combinations. Our results thus cover all plausible future pathways of sediment dynamics in the delta based on current knowledge. Our results indicate that hydropower development dominates the changes in floodplain sediment dynamics of the Mekong Delta, while sea level rise has the smallest effect. The floodplains of the Vietnamese Mekong Delta are much more sensitive to the changes compared to the other subsystems of the delta. The median changes of the three drivers combined indicate that the inundation extent would increase slightly, but the overall floodplain sedimentation would decrease by approximately 40%, and the sediment load to the South China Sea would diminish to half of the current rates. The maximum changes in all drivers would mean a nearly 90% reduction of delta sedimentation and a 95% reduction of the sediment reaching the sea. Our findings provide new and valuable information on the possible future development of floodplain hydraulics and sedimentation in the Mekong Delta and identify the areas that are most vulnerable to these changes.

1. Introduction

The Mekong Delta (MD) sustains the livelihood and food security of millions of people in Vietnam and Cambodia. It is known as "rice bowl" of South East Asia and has one of the world's most productive fisheries (Ziv et al., 2012). This high productivity is a consequence of the annual flood pulse and large amount of suspended sediments transported by the Mekong River to its extensive floodplains (Arias et al., 2014; Lamberts and Koponen, 2008). The sediment load transported by the flood pulse to the floodplains provides nutrients for agriculture and plays a major role for the high biodiversity in the whole delta system. However, recent assessments classify the MD among the most vulnerable regions in the world due to climate change related sea level rise (Watson et al., 2013) and other human activities linked to the economic development of the six countries in the Mekong River Basin (MRB) (Syvitski and Saito, 2007; Syvitski et al., 2009). The ongoing hydropower development in the MRB impacts the flow regime (Lauri et al., 2012; Piman et al., 2013) and changes the sediment load entering the MD (Kummu et al., 2010; Kondolf et al., 2014). Economic development within the delta induces land subsidence, which in turn enhances the effect of climate change related sea level rise (Ericson, 2006; Syvitski, 2008; Syvitski et al., 2009; Doyle and Day, 2010).

In total, 136 hydropower plants are being built or planned throughout the MRB. According to the current plans, 31 dams are under construction, 82 dams will be completed within 20 years and nearly all of the 136 dams will be built within the coming 40 years (MRC, 2011b). These dams will trap considerable amounts of sediments, which in turn is very likely to strongly reduce the sediment input to the delta (Kummu et al., 2010; Kondolf et al., 2014). There is a particularly strong hydropower development in the Chinese part of the MRB known as the Langcang cascade (Fig. 1), which comprises approximately only 23% of the total basin area and provides 15% of the total annual flow volume, but is responsible for 65% of the total suspended sediment load (Kummu et al., 2010). A number of studies have estimated the consequences of hydropower

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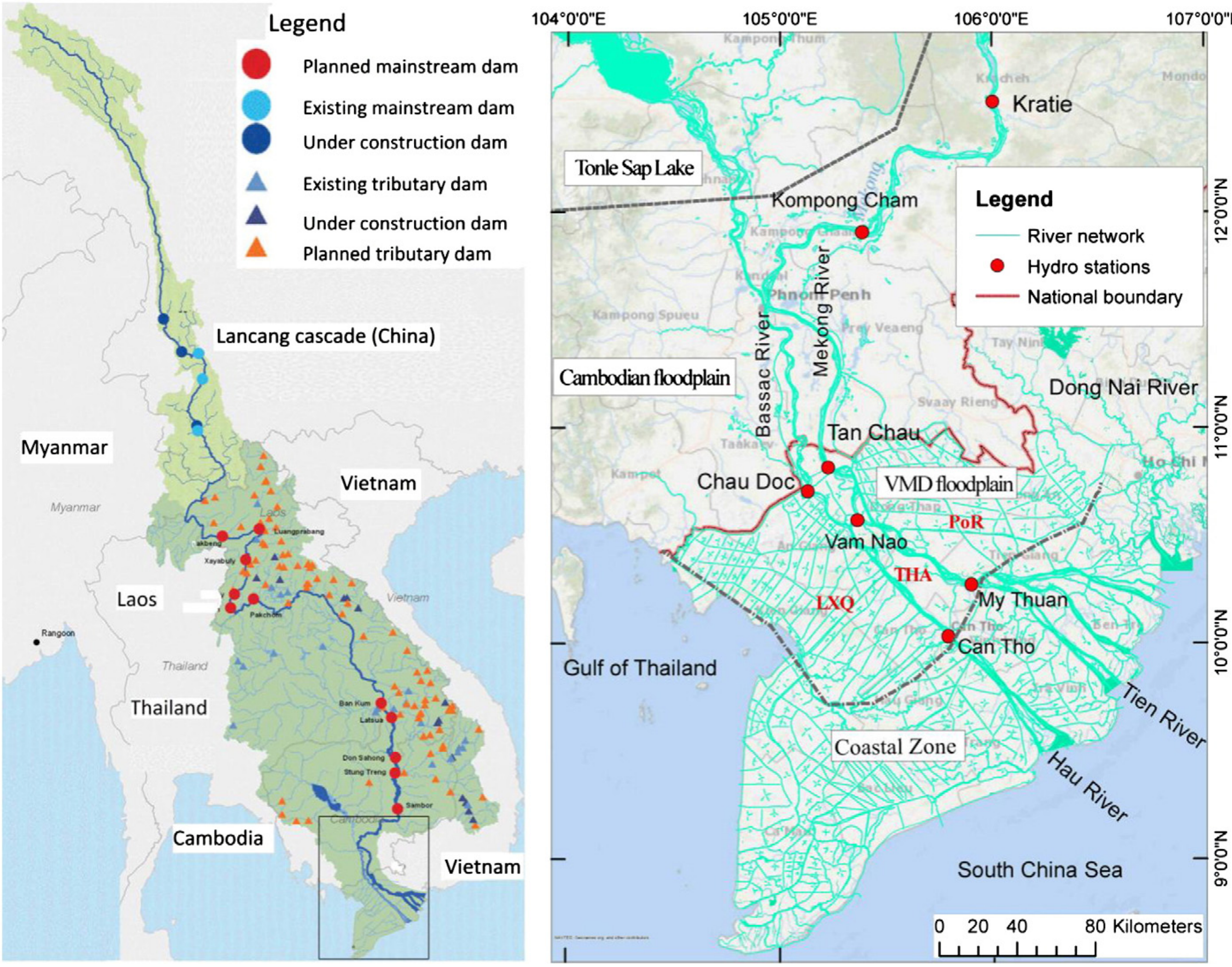

Fig. 1. Left panel: the Mekong River Basin including the hydropower dam locations (MRC, 2011b). Right panel: the Mekong Delta (MD) from Kratie to the seas including the main hydrological stations, the subsystems of the MD and the floodplain areas in the VMD.

development in the Lancang River on sediment load (Lu and Siew, 2006; Fu and He, 2007; Fu et al., 2008; Kummu and Varis, 2007; Walling, 2008; Liu and He, 2012; Liu et al., 2013; Kameyama et al., 2013). The sediment load reduction of reservoirs is commonly quantified by sediment trapping efficiency (TE). These studies find TE values of the Lancang cascade being within the range of 80–90% just downstream of the cascade and of approximately 50% at the Mekong Delta. An implementation of all 136 dams across the whole Mekong Basin is likely to result in massive reduction of sediment load in the Mekong Delta. Estimated TE varies from 78–81% by Kummu et al. (2010) to 85–90% by ICEM (2010) and 96% by Kondolf et al. (2014). Hydropower development will also alter the flow regime in the lower MRB and will increase the flows in the dry season and decrease those in the wet season (Keskinen et al., 2012; Räsänen et al., 2012; Lauri et al., 2012; Piman et al., 2013).

Climate change is expected to act as another main driver changing the hydrology in the MRB (Eastham et al., 2008; Hoanh et al., 2010; Västilä et al., 2010; Kingston et al., 2011; Lauri et al., 2012); however its impact on the flow regime of the Mekong River is highly uncertain (Lauri et al., 2012; Kingston et al., 2011). Hoanh (2010) and Västilä et al. (2010) use only one Global Circulation Model (GCM) and thus their findings are not reflecting GCM uncertainty as shown in Kingston et al. (2011) and Lauri et al. (2012). Eastham et al. (2008) examine eleven GCMs but they do not, however, downscale the GCM output to the MRB and their results are thus associated with very large uncertainty. Impact studies which have used a GCM ensemble approach along with downscaling have obtained a large range in future Mekong streamflow (Kingston et al., 2011; Lauri et al., 2012), mainly as a consequence of different GCMs. Kingston et al. (2011) study the uncertainty resulting from different GCMs and different global warming assumptions on the flow at the Mekong River gauge Pakse having a more reliable historical discharge record compared to the next downstream station Kratie, which indicates the upper boundary of the MD. Lauri et al. (2012) used two emission scenarios and five GCMs to illustrate effects and uncertainties of climate change projections and compared this to the expected changes caused by hydropower development. For the period 2032–2042, they find that hydropower development is very likely to have a much larger impact on the flow regime, particularly on the lower Mekong basin, compared to projected climate change impacts.

Another important driver of changes in the hydrology and sediment dynamics of the MD is sea level rise (SLR). The flow regime and consequently the sediment dynamics of the delta are sensitive to changes in sea level (Manh et al., 2014). Higher sea levels would cause higher backwater effects, which in turn alter the water levels and flow velocities in the river system and the floodplain inundation. As a consequence also the sediment dynamics, i.e. the erosion and sedimentation, is expected to change, with distinct spatial differences. Also the flood hazard in the delta is likely to change with higher sea levels. For deltaic regions