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Changing sediment budget of the Mekong: Cumulative threats and management strategies for a large river basin

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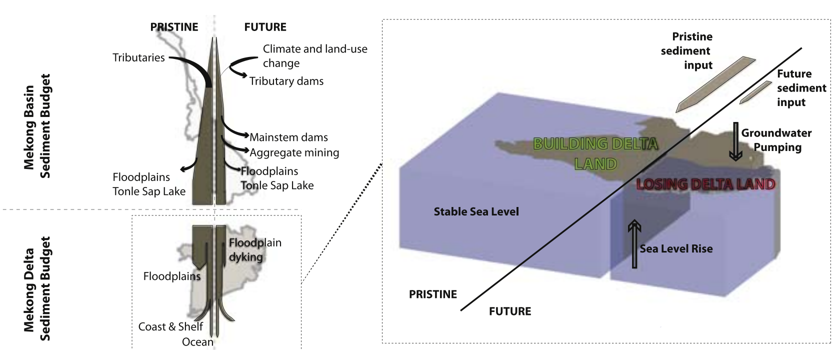
HIGHLIGHTS

- Many Mekong basin ecosystem services depend on sediment.
- Anthropogenic changes to basin sediment budget threaten basin livelihoods.
- Highest cumulative threat is to lower Mekong floodplains and the Delta.
- The Delta is a recently deposited landform (<7 ka) vulnerable to subsidence/erosion.
- The Delta's > 17 M population and thriving economy are existentially threatened.

GRAPHICAL ABSTRACT



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ABSTRACT

Two decades after the construction of the first major dam, the Mekong basin and its six riparian countries have seen rapid economic growth and development of the river system. Hydropower dams, aggregate mines, flood-control dykes, and groundwater-irrigated agriculture have all provided short-term economic benefits throughout the basin. However, it is becoming evident that anthropic changes are significantly affecting the natural functioning of the river and its floodplains. We now ask if these changes are risking major adverse impacts for the 70 million people living in the Mekong Basin. Many livelihoods in the basin depend on ecosystem services that will be strongly impacted by alterations of the sediment transport processes that drive river and delta morpho-dynamics, which underpin a sustainable future for the Mekong basin and Delta.
Drawing upon ongoing and recently published research, we provide an overview of key drivers of change (hydropower development, sand mining, dyking and water infrastructures, climate change, and accelerated subsidence from pumping) for the Mekong's sediment budget, and their likely individual and cumulative impacts on the river system. Our results quantify the degree to which the Mekong delta, which receives the impacts from the entire connected river basin, is increasingly vulnerable in the face of declining sediment loads, rising seas and

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subsiding land. Without concerted action, it is likely that nearly half of the Delta's land surface will be below sea level by 2100, with the remaining areas impacted by salinization and frequent flooding. The threat to the Delta can be understood only in the context of processes in the entire river basin. The Mekong River case can serve to raise awareness of how the connected functions of river systems in general depend on undisturbed sediment transport, thereby informing planning for other large river basins currently embarking on rapid economic development.

1. Introduction

The Mekong is among the world's ten largest rivers, both in terms of its flow discharge and its sediment load (Gupta and Liew, 2007). The diverse geographic settings of its 795,000 km^2 drainage area range from the Tibetan highlands to the vast floodplains that dominate in Cambodia and Vietnam, while its pronounced flood-pulse hydrology makes it a hotspot for biodiversity (Gupta and Liew, 2007; Kummu and Sarkkula, 2008; Campbell, 2009a; Hortle, 2009). What sets the Mekong apart from many other large rivers is the very high number of livelihoods that it supports through a wide array of ecosystem services. Many of the basin's 70 million inhabitants live close to the river and depend on complex and still poorly understood interactions among river hydrology, sediment transport, and river morpho-dynamics (Hortle, 2009; MRC, 2010). The Mekong Delta is not only among the world's largest river deltas, but also supports a population of >17 million people and produces agriculture and aquaculture of regional importance (Guong and Hoa, 2012; Renaud and Künzer, 2012; Szabo et al., 2016). Its population vulnerable to global climatic change and sea level rise is nearly unparalleled, as nearly half of the delta land surface (20,000 km^2) is <2 m above sea level (Syvitski, 2009).

The Mekong River Basin is shared among six riparian nations (China, Myanmar, Laos, Thailand, Cambodia, and Vietnam). Political struggles and wars delayed the basin's economic development until the 1990s, when the Manwan hydroelectric dam was built on the Lancang River, China (Xue et al., 2011). The Mekong Basin has since experienced rapid economic development, manifested through a substantial expansion of dams and hydropower, intensification of aggregate mining, expansion of dykes and irrigated agriculture, urbanization and exploitation of groundwater resources, all intended to promote development and extract economic value for the six nations through which the Mekong flows.

For example, Laos aims to become the “battery” of south-east Asia through a massive expansion of its dam infrastructure and hydropower production. Vietnam has invested in the construction of higher dykes to increase crop production in the Delta (Chapman et al., 2016), along with increasing ground-water pumping rates (Erban et al., 2014; Minderhoud et al., 2017). China is developing a dense cascade of dams along the upper Mekong for both hydropower and improved navigation (Räsänen et al., 2017). In Cambodia, aggregate from floodplains and channels provides a valued commodity for export, and some mega-dam sites along the mainstem Mekong offer significant hydropower production potential (Bravard et al., 2013; Wild et al., 2016).

Each of these actions might create some immediate economic benefits for the developer. However, alone and in accumulation, these projects also create negative environmental externalities that do not stop at dam or mining sites, but extend beyond country boundaries and accumulate and amplify over the entire Mekong Basin. Most developments will impact various aspects of the ecologic and geomorphic functioning of the river, ranging from obstructed fish migration and altered hydrologic regimes, to reduced sediment transport and connectivity. The impact of these disturbances within the basin might be amplified by global climate change and higher sea levels.

As the Mekong basin supports such a large number of human livelihoods and highly diverse ecosystems, understanding the cumulative impacts of the anticipated disturbances is essential for identifying the most detrimental practices, planning for early adaptation, and minimizing future impacts on human livelihoods. Many of the Mekong's ecosystem services, and the livelihoods they support, are driven by a continuous flux of sediment from the upstream catchment to the downstream floodplains and the delta. Sediment provides the building material for floodplains and in-channel habitat. An annual flood-pulse distributes fine sediment and sediment-bound nutrients to the Mekong floodplains and the Tonle Sap Lake, supporting one of the most diverse and highest yielding inland fisheries anywhere in the world (Lamberts, 2006). The sediment delivery from the Mekong River built the entire Mekong Delta landform during the Holocene.

Now in the third decade since the onset of accelerated development in the Mekong Basin, significant changes are manifest in the river basin's sediment budget and geomorphic processes. A substantial scientific effort over the last decade has yielded a significant body of knowledge about human impacts on the Mekong's sediment budget and observations of geomorphic processes. However, there is still a lack of a high-level overview regarding the ecosystem services provided by geomorphic and sediment transfer processes in the Mekong, and the cumulative impacts of resource use and development in the basin on these processes.

We base this paper on the concept that sediment dynamics in the Mekong River provide the geomorphic template upon which both human livelihoods and ecosystems are built in the Mekong basin and its delta, and that understanding human impacts on geomorphic processes is key to protecting river and delta ecosystems. In this paper, we identify resource-use practices with the greatest impacts, the cumulative impacts of disturbance, and areas where changes in geomorphic processes will have the greatest impact. We also outline potential opportunities for more sustainable management. Such a high-level assessment of potential synergies in both threats and management responses may be informative for other basins where extensive development has begun, such as the Amazon or the Congo (Winemiller et al., 2016).

We first provide an overview of the geography and natural sediment transport dynamics of the Mekong River basin and discuss the value of ecosystem services extracted from the river, its floodplains, and delta. We then analyze four major drivers behind changing sediment transport and morpho-dynamics, namely damming, sand mining, dyking of floodplains, and groundwater pumping. The delta, which hosts the largest population and largest agricultural production in the basin, will accumulate impacts of upstream disturbance and suffer additionally from global climatic changes and sea level rise. Hence, we conclude with an overview regarding potential futures of the delta landform as a whole, and potential management responses.

2. Geographic setting and socio-economic importance of the Mekong River Basin and its delta

2.1. The Mekong River Basin

The Mekong River (its upper reach in China is known as the Lancang) drains 795,000 km^2, dropping around 4000 m from its narrow headwater catchment on the Tibetan Plateau through bedrock canyons in Yunnan Province of southwest China and along the border with Burma. Then the Mekong drops around 500 m as it flows through Laos, Thailand, Cambodia, and Vietnam *en-route* to its delta in the