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Interplay between land-use dynamics and changes in hydrological regime in the Vietnamese Mekong Delta

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ABSTRACT

Policies supporting rice production and investments in water infrastructure enabled intensification and diversification of farming systems in the Vietnamese Mekong Delta (VMD) over the past 20 years. Yet, demands of food security, economic development, and climate change continue to pose diverging and often conflicting challenges for water resources management in the upper, central, and coastal zones of the delta. The major changes effected in the VMD's hydrological regime and land-use patterns are acknowledged in the literature, but few studies have examined the interplay between these dynamics at the delta scale. Based on time-series maps and statistical data on land-use, flooding, and salinity intrusion, we investigated the interrelations between land-use dynamics and changes in hydrological regime across the VMD in three representative periods. Land-use was found to be highly variable, changing by 14.94% annually between 2001 and 2012. Rice cropping underwent the greatest change, evolving from single cropping of traditional varieties towards double and triple cropping of high-yielding varieties. Aquaculture remained stable after rapid expansion in the 1990s and early 2000s. Meanwhile, flooding and salinity intrusion were increasingly controlled by hydrological infrastructure erected to supply freshwater for agriculture. Effects of this infrastructure became particularly evident from 2001 to 2012. During this period, spatial and temporal impacts on flooding and salinity intrusion were found, which extended beyond the rice fields to affect adjacent lands and livelihood activities. Unforeseen effects will likely be aggravated by climate change, suggesting a need to rethink the scale of planning towards a more integrated hydrologic approach.

1. Introduction

Surface water, including reservoir water and stream flows, is essential for human activities, particularly for agriculture, forestry, and fisheries. Indeed, land-use and water resources are reciprocally related and mutually dependent. Water availability shapes land-use patterns; and the way that land is utilized affects water supplies and quality. As discussed by Calder (2005), afforestation, intensive agriculture, and urbanization have changed hydrological regime, leading to diminished water quality in developing countries. This has contributed to changes in the global hydrological cycle, which in turn are considered a main factor causing erosion and more than half of the world's soil degradation—resulting in reduced agricultural land availability. Understanding how changes in land-use interrelate with changes in hydrological regime is therefore crucial, at the global and at the regional level.

The interplay between land-use patterns and water resources is particularly manifest in large deltas where agriculture is the dominant livelihood. In one such delta, the Vietnamese Mekong Delta (VMD), satellite observations from 2000 to 2007 suggest that particular farming systems have been employed to deal with seasonal variations in the water cycle (Sakamoto et al., 2009b, 2006). In the upper delta, before permanent dykes were built, farmers practised double rice cropping in the dry season to avoid the risks posed by flooding in the rainy season. In the central delta, farmers practised triple rice cropping, while also cultivating perennial crops taking advantage of the fertile alluvial soil

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and year-round availability of freshwater. In the coastal zone, farmers practised double and single rice cropping in the rainy season, as salinity intrusion and limited irrigation water constrained dry season cultivation. To adapt to the brackish conditions spanning six months of the year, many coastal farmers adopted rice-shrimp farming systems or converted their rice fields to shrimp ponds.

Over the last 20 years, seeking to increase rice production in the VMD, the Vietnamese government invested in new infrastructure to better manage the delta's hydrological regime (Tri, 2012). By 2011, dykes and sluice gates offered flood protection to most of the rice fields in the upper and central zones (Duong et al., 2014; Kuenzer et al., 2013). Dykes, sluice gates, and water supply canals were also built in the coastal zone, to prevent salinity intrusion and facilitate rice cultivation (Hoanh et al., 2012; Toan, 2014).

This greater management of the hydrological regime, alongside increasingly intensive rice farming, has raised concerns, however, about impacts on the environment and livelihood activities. Indeed, dyke construction has reduced water retention capacity throughout the upper delta, while increasing the risk of flooding and erosion downstream (Käkönen, 2008). Furthermore, the large quantities of water abstracted from rivers for intensive rice farming have worsened salinity intrusion in the coastal zone, affecting fruit orchards and rice fields as far inland as the central delta (Hashimoto, 2001; Nhan et al., 2007). In the brackish areas, the prospect of high-value shrimp production has motivated farmers to try to retain saline water in their ponds. This, however, conflicts with the needs of rice farmers and the design of hydrological infrastructure (Hoanh et al., 2003)

Recognizing the consequences of its rice-oriented agricultural policy, the Vietnamese prime minister has sought to restructure the agriculture sector. With its Resolution 899, the government has aimed to raise the added value in agriculture while promoting sustainable development (Government of Vietnam, 2013). A planning exercise has also been completed, in which the Vietnamese government cooperated with the Dutch to develop a long-term vision for the VMD (Royal Haskoning DHV et al., 2013). Both the new policy and the development vision respond to challenges of economic development and climate change. Temperature and rainfall models suggest that flooding will become increasingly difficult to forecast in the upper delta, and that rising sea levels and more frequent severe droughts will cause salinity intrusion to occur for longer periods in the coastal zone and extend farther inland (Tri et al., 2013; Trung and Tri, 2014). Meanwhile, household surveys indicate that 65% of the region's farmers anticipate continuing their current livelihood practices, including their current land-use, even if sea levels were to rise by 30 cm (Smajgl et al., 2015). In this context, a better understanding of the factors driving changes in land-use, particularly changes in the hydrological regime, could help policymakers formulate effective management plans tailored to the different agro-ecological zones of the delta, while also mitigating water-related conflicts between delta regions.

Although the general mechanisms are understood, it remains difficult to specify exactly how changing land-use patterns interrelate with changes in hydrological regime, because these systems act at different spatial and temporal scales. Remote sensing has been widely used to monitor and investigate correlations between land-use patterns and flooding at the delta scale (Kuenzer et al., 2013; Sakamoto et al., 2007). Moreover, hydrological models and GIS analysis have been applied to explore the impacts of salinity intrusion on land-use patterns within a particular hydrological system (Hoanh et al., 2006; Tuong et al., 2003). While these techniques have proven useful for studying developments in land-use patterns and hydrological regime, as well as their interactions, little research has investigated the cross-boundary interplay between these variables at the delta scale. Previous studies have looked at how changing land-use interacts with the drivers of such change, including hydrological regime, at the household and community levels, using interview and statistical data to assess the role of the different drivers (Can et al., 2007; Ha et al., 2013; Hoang et al., 2008; Renaud et al., 2015). Such localized findings, however, fall short in representing the full spectrum of relations at the delta scale, particularly for a delta as complex as the VMD, with its range of agro-hydrological zones.

The current study sought to deepen insight on the land-water relationships throughout the VMD. Using secondary sources, such as scientific reports, statistical data, and maps, we systematically investigated the characteristics of land-use dynamics, hydrological regime, and the interactions between these in the VMD over three representative study periods extending from prior to 1995 to 2012.

2. Study area

The VMD spans 39,700 square km and is home to nearly 18 million people. This fertile delta produces more than half of Vietnam's rice output. Some 64% of the delta is devoted to agricultural purposes (GSO, 2012), and 69% of its labourers work in agriculture, forestry, or fisheries (Vormoor, 2010).

There are two main river systems in the VMD, the Mekong or 'Nine Dragons' and the Vam Co. We focused on the Mekong river system, as it is the delta's most dominant. The Mekong system flows from Cambodia to Vietnam in two main streams: the Bassac river and the Mekong river, which contribute, respectively, 17% and 87% of the total annual flow. The Mekong links to the Bassac via the Vam Nao river, eventually discharging from the Bassac into Vietnam's East Sea and West Sea (Tri, 2012). The Bassac has two tributaries, while the Mekong has six tributaries. These are interconnected via a dense network of natural streams and canals. In the rainy season, water-flows increase, causing prolonged inundation of the upper delta. In the dry season, low river flows and high tide events raise the salinity of the waters and soils along the coast, making water shortages and salinity intrusion serious problems.

This seasonal regime has played a key role in the delta's agricultural development. Floods and water flows have been managed by water infrastructure since the early 19th century. The first canal network and waterways that shaped the VMD today were built under political efforts of the Vietnamese and French authorities as well as the American army. After the end of the Vietnam War in 1975, hydraulic works continued to be conducted by the government and locals (Biggs, 2011; Evers and Benedikter, 2009; Hoanh et al., 2010). To utilize and manage water flows, a huge infrastructure has been built, including 15,000 km of main canals, 27,000 km of secondary canals, 50,000 km of on-farm canals, 80 large sluice gates, 13,000 km of flood-prevention dykes, 1290 km of salinization-prevention dykes, and 450 km of sea dykes (SIWRP, 2011).

The dominance of rice cultivation in the VMD nowadays is a product of explicit government policy to ensure food security, which was initiated after the 1980s, when the country became a net rice importer. Much of its current flood- and salinization-control infrastructure was completed or has been upgraded since 1990. The resulting improved water management has enabled triple rice cropping on the floodplains and in brackish zones of the delta. Moreover, enlargement of canals and drainage systems has allowed farmers to reclaim areas with acid sulphate soils for rice cultivation. These hydrological interventions, while expanding the region's agricultural potential and boosting rice output, have also led to natural resources degradation and affected farmers' livelihood options (Käkönen, 2008).

3. Materials and methods

We analysed changes in land-use patterns and the hydrological regime in the VMD based on three representative periods, which were derived from literature documenting historical events affecting these variables. The literature includes scientific articles and book chapters related to topics of 'land-use change', 'farming systems', 'water resources management', 'flood management', and 'salinity intrusion' in the VMD. Our review particularly explored reports of the Southern