IMPACT OF ENSO ON WATER DISCHARGE AND SEDIMENT LOAD IN LOWER MEKONG RIVER

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Received: 3 November 2018; Accepted 25 December 2018

Abstract: *The Mekong River is the second largest river basin in Southeast Asia and strongly influenced by climate change. This paper was based on high temporal resolution of water discharge and suspended sediment concentration at Can Tho and My Thuan stations during the 2009-2016 period, showed that the water discharge and sediment supplies by the Mekong strongly varied, and influenced by ENSO events (El Nino Southern Oscillation). Our results obtained showed that during the La Niña event (2010-2011), water supply increased by about 30% and the sediment supply by 55%. In contrast, during the El Niño event (2015-2016) the water supply decreased by 20% and the sediment supply by 50%. Finally, the present water discharge of the Mekong River to the sea can be estimated to be 400km^3/yr, ±100km^3/yr and the present sediment supply to the sea can be estimated to be 40 Mt/yr, ±20 Mt/yr, depending on ENSO events.*

Keywords: *Mekong; river discharge; sediment; ENSO; El Niño; La Niña*

1. Introduction

The Mekong River is the second largest river basin (795×103km^2) after the Yangtze River (1.8×106km^2) and the third in terms of water discharge (after the Ganges-Brahmaputra and the Yantgze Rivers) in Southeast Asia. In recent years, reservoir operation and climate change have strongly affected on hydrological regime of the Mekong River Basin. Many studies have analyzed the impact of climate variability on hydrological conditions in the Mekong River basin and the El Niño Southern Oscillation (ENSO) indices were widely used (e.g. [2,4,5]). They showed that the ENSO phases significantly influence precipitation, runoff, water level and sediment load in the Mekong River basin. Piton and Delcroix [2], based on data from 43 consecutive years of in situ measurement (1960-2002) and seven years of satellite monitoring (1996-2002), demonstrated that El Niño phases were associated to a decrease in rainfall in the middle and lower Mekong basin and to a reduction of water discharge at the Chroy Chang Var station (located in Cambodia). The discharge reduction reached 34% during the strong 1997-1998 El Niño. On the other hand, higher discharges were observed during La Niña events [8].

The Mekong River originates from the Tibetan plateau and flows through a narrow deep gorge along with the Salween and Yangtze Rivers that together are known as the "Three Rivers Area". The Mekong River then flows through Myanmar, Laos, Thailand, and Cambodia before it finally drains into the sea creating a large delta in Viet Nam (Figure 1). The Mekong flows in the delta through two main distributaries: the Tien River (generally referred to as the Mekong River, in the delta) in its eastern part, and the Hau River (the "second river" in Vietnamese, also known as Bassac River) in its western part.

The river discharge of the Mekong is mostly controlled by the tropical monsoon climate, which has distinct wet and dry seasons. Mean annual rainfall varies from 1,000mm in Thailand to 3,200mm in Laos. In the Mekong River basin, 85% of water discharge occurs

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during the flood season and 15% occurs in the low flow season. The discharge is the largest from August-September and the smallest in April-May [7].

This paper is based on the recent extensive dataset of hourly water discharges and twice-daily sediment concentrations, from 2009 to 2016 at 2 strategic sites (Can Tho and My Thuan gauging stations- Figure 1), supplied by the Viet Nam Institute of Meteorology, Hydrology and Climate change (IMHEN). The aim of this study is to analyse the influence of climatic variability on water discharge and sediment flux in the Lower Mekong River.

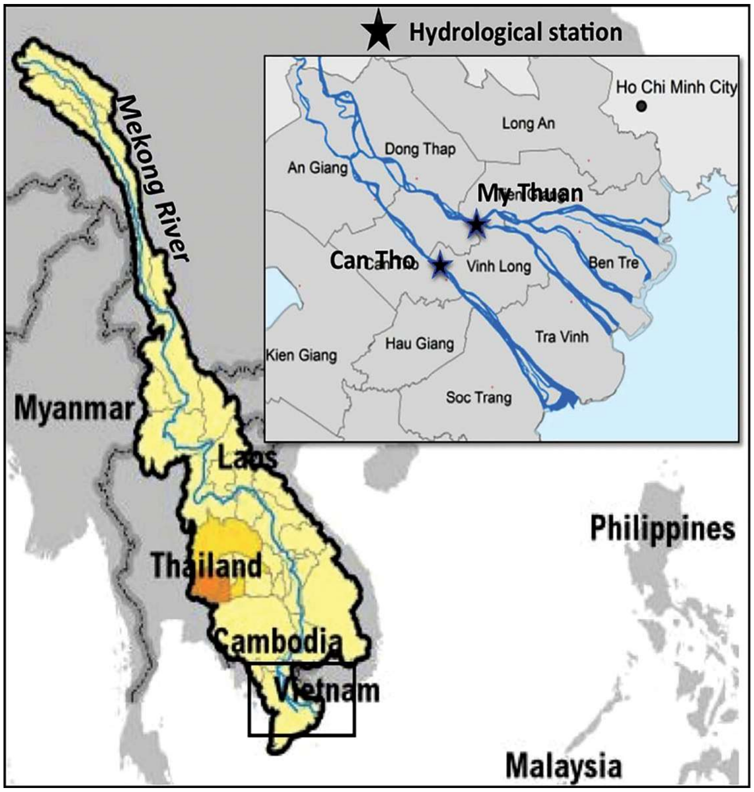

Figure 1. Hydrological network of the Mekong River Basin

2. Data collection and treatment

The sediment flux in ebb tide and flood tide conditions were calculated following:

$Q_{s,e} = Q_e \times C_{av,e}$ and $Q_{s,f} = Q_f \times C_{av,f}$

where Q stands for the water supply during an ebb or flood period, Qs for the suspended sediment supply during this period, Cav for the average suspended sediment concentration, and subscripts e and f stand for ebb and flood, respectively.

The monthly net sediment flux (Qs j, in Mt/month) of month j was then computed from the contributions of all ebb tides and flood tides of the month:

$$Qs_j = \sum_{i=1}^{i=n} Qs._{ei} - \sum_{i=1}^{i=n} Qs._{fi}$$

where n stands for the number of days in month j, and the annual sediment flux (Qs_a, in Mt) from:

$$Qs_a = \sum_{j=1}^{12} Qs_j$$

For the information of climatic variations, in particular to assess the impact of ENSO on the water and sediment supplies, different indexes were considered, provided by the National Oceanic and Atmospheric Administration (NOAA, e.g. Sea Surface Temperature - SST, Southern Oscillation Index - SOI,…) and the Southern Oscillation Index (SOI) was often used [1,2,6]. Prolonged periods of negative SOI values coincide with abnormally warm ocean waters across the eastern tropical Pacific typical of

El Niño episodes, whereas prolonged periods of positive SOI values coincide with abnormally cold ocean waters across the eastern tropical Pacific typical of La Niña episodes. Sustained positive SOI values above about +8 indicate a La Niña event while sustained negative values below about –8 indicate an El Niño.

In this paper, the data of SOI was downloaded from the website https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml [5]). The Figure 2 displays the ENSO events using monthly SOI anomalies. Based on time series of SOI anomaly between 2009 and 2016 in Figure 2, we observed one obvious El Niño event (2010-2011) and one obvious La Niña event (2015-2016).

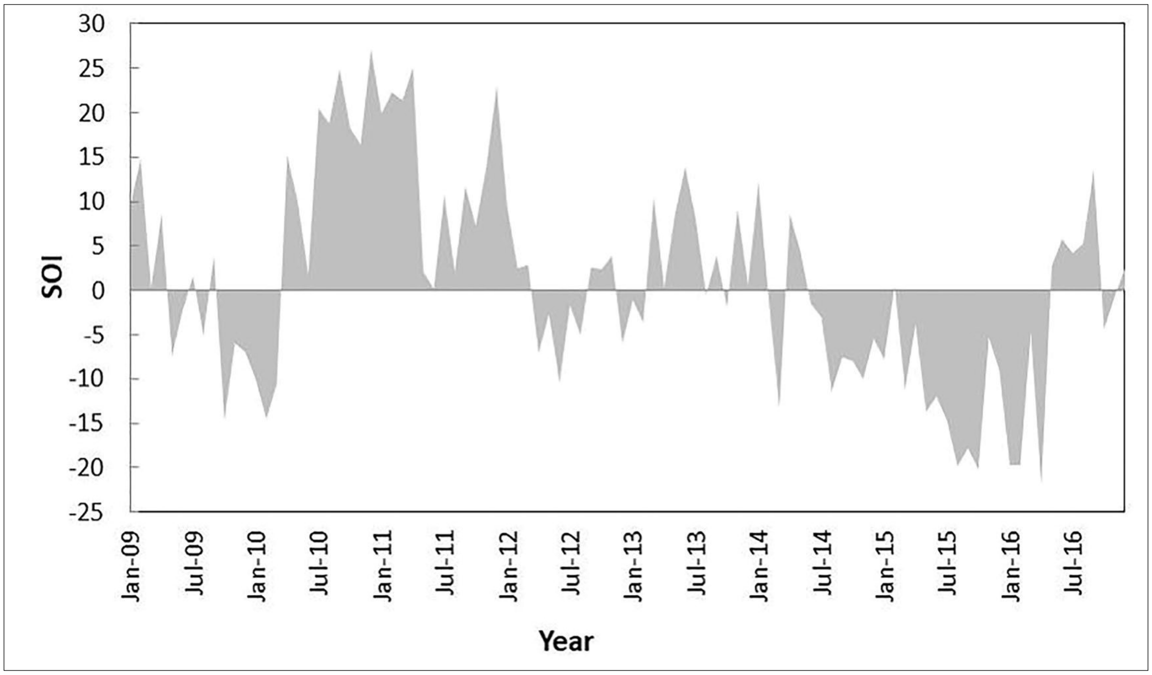

Figure 2. Time series of SOI anomalies. Positive SOI values above about +8 indicate a La Niña event while negative values below about - 8 indicate an El Niño

3. Results and Discussions

3.1. Monthly Averages and Annual Variations of Flux - in and flux Out in the Estuaries

The monthly and yearly values of sediment flux flowing seaward (flux-out) and landward (flux-in) at CanTho and MyThuan stations were calculated over the eight-year monitoring period (2009-2016) and are presented in Figures 2 and 3. We observed that the monthly evolution of sediment flux flowing seaward and landward at both stations experienced strong seasonal variations (Figure 2). At the Can Tho station, the monthly sediment flux-out ranged between 0.14 and 10.5 Mt/month (average value of 1.5 Mt/month) with the highest value observed in rainy season. The highest values of sediment flux-in were observed in dry season with individual values varying from 0.01 to 0.45 Mt/month (average value of 0.16 Mt/month). A similar evolution of sediment flux-in and-out was observed at the My Thuan station (Figure 3).

The trend to a decrease in the yearly flux flowing out (Figure 4) should be analyzed with care, since the study period encompassed an excess of discharge at the beginning of the study period with the La Niña event of 2010-2011, and ended with a deficit of discharge associated to the El Niño event of 2015-2016. The trend is almost nil at Can Tho, while a short increase in landward sediment flux was observed at My Thuan station, showing slight impact by the ENSO variation in My Thuan (Figure 4). The difference in the trends between the two stations may be partly explained by other factors than El Niño, such as sand mining activities [1, 3].

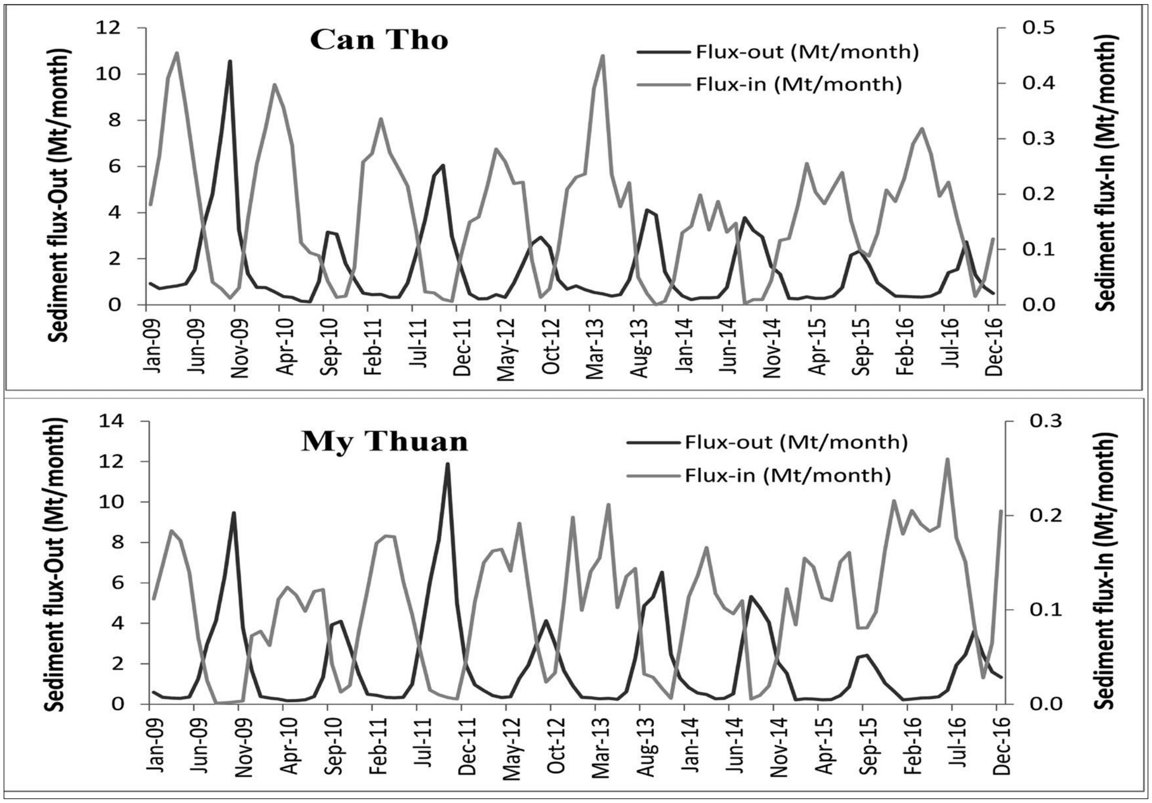

Figure 3. Evolution of monthly sediment fluxes oriented seaward and landward at Can Tho and My Thuan stations for the period 2009-2016

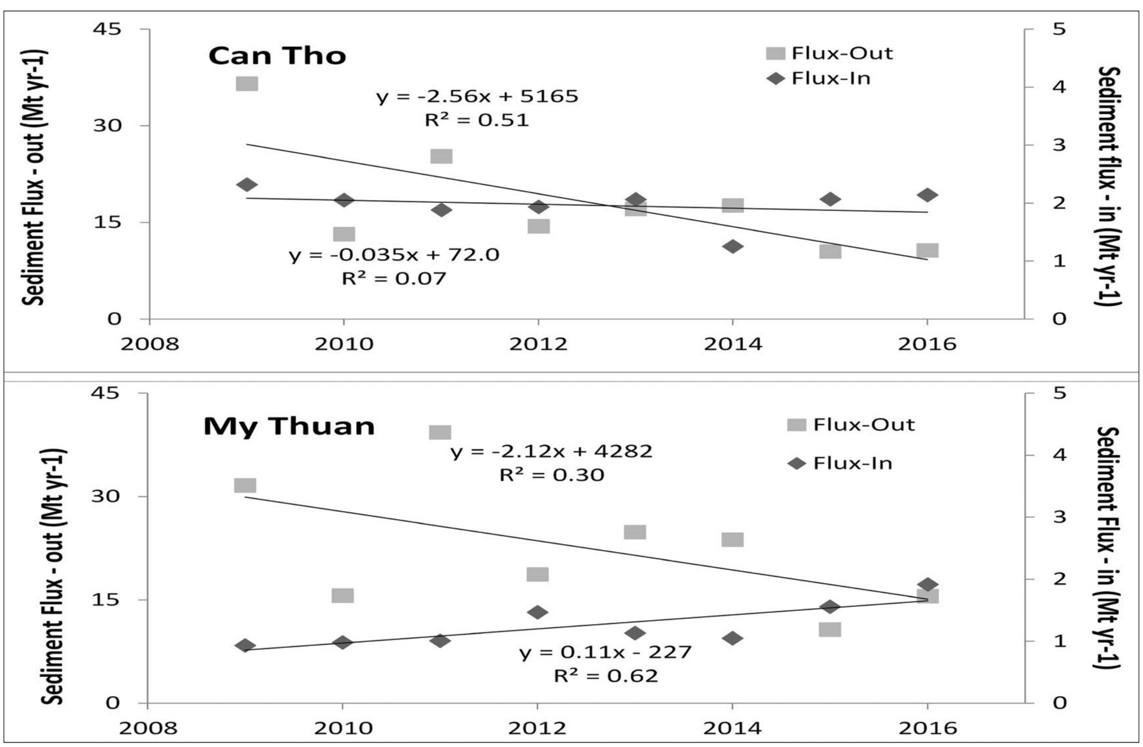

Figure 4. Evolution of annual sediment fluxes oriented seaward and landward at Can Tho and My Thuan stations for the period 2009-2016

3.2 Influences of ENSO on Seasonal and Annual Sediment Supply

In order to assess the influence of ENSO on suspended sediment fluxes at monthly and annual scales, we compared the monthly and yearly values of 2010-2011 (affected by the 2010 La Niña, Figure 2), 2015-2016 (affected by the strong 2015 El Niño, Figure 2), to the ones averaged over 2009 and 2012-2014. The monthly values are presented in Figure 5, and the yearly averaged values, per period, for Q and Qs, are given in Table 1.

The influence of El Niño and La Niña on the monthly and yearly Q and Qs are very clear in comparison with neutral years:

- In 2010-2011 (affected by La Niña of 2010), the flux of water flowing to the sea of the Mekong River (Can Tho + My Thuan) increased by ~22% and the flux of water entering in the estuaries decreased by more than 10%. Globally, the net seaward flux of water increased by 29.6%. The sediment supply by the river increased by ~51% and the sediment flux inland decreased by 15%, providing a net increase of sediment supply to the sea by 55.6%.

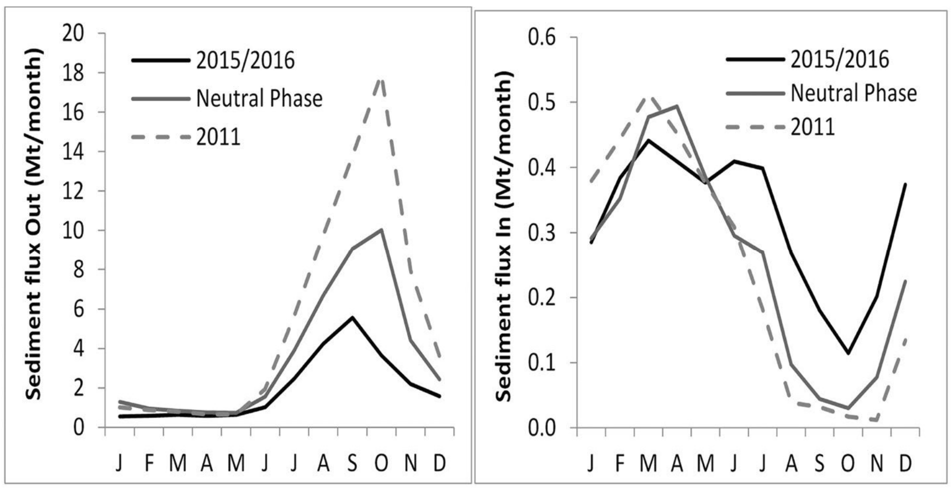

Figure 5. Monthly evolution of the sediment flux-out and flux-in of the Mekong River

Table 1. Average yearly water and sediment discharges at Can Tho and My Thuan stations during different ENSO stages over the 2009-2016 period. (in km^3/yr; ** in Mt/yr)*

Period	Can Tho			My Thuan			Can Tho + My Thuan		
	Flux In	Flux Out	Total	Flux In	Flux Out	Total	Flux In	Flux Out	Total
Q 2010-2011 (La Niña)*	47.9	290.2	242.3	36.7	307.9	271.2	84.6	598.1	513.5
Q 2015-16 (El Niño)*	70.7	221.1	150.4	57.1	221.6	164.5	127.8	442.7	314.9
Q 2009,2012-2014 Neutral phase*	54.4	245.2	190.8	40.4	245.6	205.2	94.9	490.9	396.0
Qs 2011 (La Niña)**	1.88	25.25	23.37	1.01	39.33	38.32	2.89	64.58	61.69
Qs 2015-16 (El Niño)**	2.11	10.58	8.47	1.74	13.13	11.39	3.84	23.70	19.86
Qs 2009,2012-2014 neutral phase**	1.93	19.77	17.85	1.11	22.91	21.80	3.04	42.68	39.65

- In 2015-2016 (affected by El Niño of 2015), the flux of water flowing to the sea of the Mekong River (Can Tho + My Thuan) decreased by ~10% and the flux of water entering in the estuaries increased by more than 34%. Globally, the net seaward flux of water decreased by 20.5%. The sediment supply by the river decreased by ~45% and the sediment flux inland increased by 26%, providing a net decrease of sediment supply to the sea by 50%.

The flux back to the estuaries evolves the opposite of the flux seaward. The effect of ENSO on the sediment fluxes (in and out) is mainly sensitive in flood season (Figure 5).

In conclusion, the water flux to the sea was 396km^3/yr, and the sediment supply to the sea was 39.65Mt/yr in average over the neutral years. La Niña was seen to increase the water supply by almost 30% and the sediment supply by 55%. El Niño was seen to decrease the water supply by 20% and the sediment supply by 50%.

4. Conclusions

The benefit of regular measurements at each flood and ebb stages from 2009 to 2016 is to provide, for the first time, an estimate of both sediment fluxes flowing seaward and landward in the estuaries. Our results showed that during 2009-2016 period at both stations measured, the monthly sediment flux flowing seaward was very high in rainy season. In contract, the highest values of monthly sediment flux landward were observed in dry season. The present water discharge of the Mekong River to the sea can be estimated to be 400km^3/yr, ± 100km^3/yr depending on ENSO, and the present sediment supply to the sea can be estimated to be 40Mt/yr, ± 20Mt/yr, depending on ENSO.

In added, we observed that the water discharge and annual sediment supplies by the Mekong strongly influenced by ENSO events. In fact, the water supply increased by almost 29.6% and the sediment supply by 55.6% due to La Niña event of 2010-2011; the water supply decreased by about 20.5% and the sediment supply by 50% due to El Niño event of 2015-2016. However, we noted that the long-term observation (>10 years) is needed in order to deeply analyse the impacts of the climatic change on the hydrological regime in the lower Mekong River.

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