SUSPENDED SEDIMENT DYNAMICS IN THE CHI-MUN RIVER BASIN, THAILAND: IMPACT OF CLIMATE CHANGE AND ANTHROPOGENIC ACTIVITIES

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The Mekong River delta, the world's third largest delta and the most important to the food security of Southeast Asia, has been increasingly affected by largescale shoreline erosion and land loss due to a decrease in sediment supplies. To mitigate and respond to the shoreline changes and loss of coastal ecosystems in the Mekong River Delta, understanding the trends in suspended sediments in sub-Mekong River Basins and implementing effective sediment management strategies are needed. The Chi-Mun River Basin, situated in North Eastern Thailand, is the largest tributary on the right bank of the Mekong River. However, dynamics of suspended sediment in the Chi-Mun River basin has not been fully understood. This study aims to estimate suspended sediments and investigate their trends in the Chi-Mun River Basin. In delivering the aims, suspended sediments were estimated from Landsat 5 (TM) and Landsat 8 OLI acquired between 1992-2017 using empirical equations derived from significant relations of 26 field-measured water spectra and measured suspended sediment *[R^2=0.92]*. The estimated suspended sediments from remote sensing were validated using 16 field measured suspended sediments, which the estimated values closely followed the tendency of measured values *[R^2=0.74]*. The variations of estimated suspended sediment level in the Chi-Mun River basin are related to seasonal changes. An increase in suspended sediment level was observed in rainy season (May-Oct), while a decrease in suspended sediment level was observed in dry season (Nov-Apr). However, increase in suspended sediment can be found during dry months as a result of urban sediments supply to the river coupled with dam draining. Overall trend of suspended sediment level in this river basin gradually declines corresponding with declining in overall annual precipitation pattern. In addition, the water abstraction along the Mun River also play a key role in trapping of suspended sediment resulting in decrease amount of suspended sediments flow into the Mekong River. Remote sensing technology is a great tool provides more understanding of suspended sediment dynamics and their response to climate changes and anthropogenic activities in the Chi-Mun River basin. The information obtained from the technology can be used to help establish sediment management strategies in response and mitigation to changes in coastal ecosystem at the Mekong River delta.

1. INTRODUCTION

Suspended sediment plays an important role in aquatic environment (Newcombe and MacDonald, 1991). It is not only an important factor in determining water quality, it also a critical factor causing riverine and coastal ecosystem changes (Hauer et al., 2018). A large amount of suspended sediment in the river can cause decrease in light penetration resulting in low biological productivity. As nutrients are carried by the fine fraction in sediments, increase in suspended sediment in the river also aggravates eutrophication and occurrence of harmful algal blooms in aquatic ecosystem (Bilotta and Brazier, 2008, Hauer et al., 2018). In addition, excessive sedimentation in river channels causes change in flow pattern and water drainage capacity leading to flood risk (Happ, 1944). Sedimentation also reduces invertebrate drift and fish mobility which impacts on human life along the river (Bilotta and Brazier, 2008). In contrast to the river ecosystem, increase in a net transport of suspended sediment towards a river delta is necessarily required as it can help protect coastal erosion from high energy waves during storm events (Temmerman et al., 2013). Furthermore, suspended sediment is necessary for mangrove forest, nurseries for many fish species, to build soils in which to grow (Furukawa and Wolanski, 1996). The Mekong River delta is one of river deltas where has been increasingly affected by largescale shoreline erosion and land loss due to a decrease in sediment supplies (Anthony et al., 2015). To mitigate and respond to the shoreline changes and loss of coastal ecosystems, comprehension of dynamics of suspended sediment in the region and establishing sediment management strategies to balance quantity of sediments is crucial and needs an effective tool which can eliminate limitations of in situ measurement techniques which time-consuming and costly (Spalding et al., 2014). Remote sensing technology can provide regular temporal observations of changes over a wide spatial area, making use of the technology to improve the spatial and temporal coverage of in situ sediment measurements is advantageous (Cracknell, 1999). There are several suspended sediment studies in the Mekong River basin (Lu and Siew, 2006, Walling, 2008, Wang et al., 2011); however, dynamics of suspended sediment in the Chi-Mun River basin, the largest sub-Mekong River basin on the right bank contributing the largest annual runoff has not been fully understood. Understanding dynamics of suspended sediment in the Chi-Mun River basin could increase better comprehension in the whole situation of suspended sediment in the Mekong River basin.

2. OBJECTIVES

- To quantify suspended sediments dynamics in the Chi-Mun River basin using remote sensing data from 1992 - 2017 (25 years)
- To understand effect of climate change and anthropogenic activities on suspended sediments dynamics in the Chi-Mun River basin

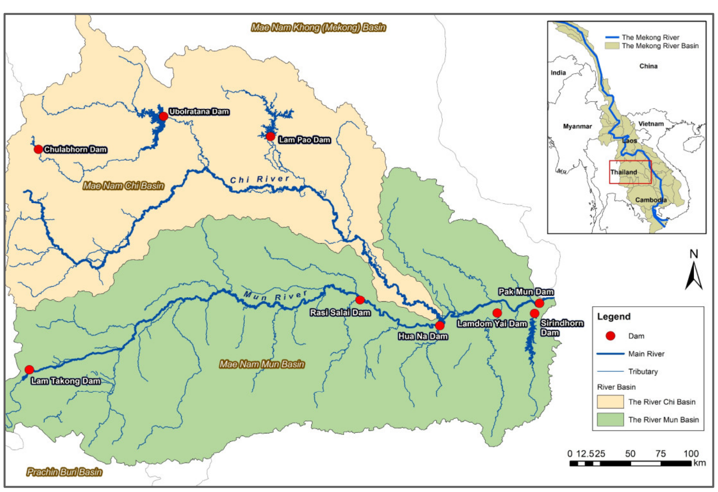


Figure 1: Map of the Chi-Mun River Basin showing location of dams along the rivers

3. STUDY AREA

The Chi-Mun river basin is a right-hand tributary of the Mekong River, located in northeast Thailand (Figure1). The drainage area of the Chi - Mun River basin covers 120,000 km^2. The basin has the two major rivers (the Mun and the Chi Rivers) flowing west to east and to the Mekong River (Floch and Molle, 2009). The basin comprises of hills, rolling lands, floodplains and levees. The weather in the basin influences by tropical monsoon. A wet season start from May to October and a dry season starts from November to April. The rainfall reaches the highest peaks in June to August and decreases continually from November to March. The highest amount of annual rainfall is found in the east while the west has the lowest (Chaleeraktrakoon and Punlum, 2010). Although the annual rainfall varies from year to year, annual rainfall in the basin is distinctly different between wet and dry periods (Floch and Molle, 2009). Soils in the basin are mostly sandy with high rates of percolation and low organic matter and soil fertility. Among the cultivated agricultural crops, paddy rice is dominant in the basin (Kuntiyawichai, 2012). There are nine dams constructed in the basin to supply water for municipal service, agriculture and hydro power-generating facilities. The six of which located in the Mun River basin while three of which located in Chi River basin (Figure1).

4. DATA SOURCES

778 Landsat -5 TM images and 167 Landsat-8 OLI images acquired from 1992 to 2017 with a maximum 20% of cloud coverage were downloaded from the Earth Explorer user interface to use in this study. Monthly suspended sediment measured at 4 stations along the Mun River from 2011-2016 by the Royal Irrigation Department, Thailand were also used in this study.

5. METHODS

5.1 Collection of field data and Total Suspended Sediment (TSS) retrieval model

The measurements of water spectra and 42 water sampling from the top 30 cm of the water column along the Mun Rivers were undertaken during dry season 30th March to 2nd April 2018. All of the water sampling location were located in the main river channel to reduce the impact reflectance of river bank (Figure2). Spectral reflectance from the water surface was measured at 1 nm intervals between 350 and 2500 nm at each of the 26 field sites along the Mun River using the ASD FieldSpec®3 Spectrometer for fitting the model. A white reference measurement was also carried out at each location before collecting water surface reflectance to reduce changes in lighting conditions between sites (Figure3). Three water spectra measurements were obtained and then averaged to get one water spectral value per wavelength per site. In addition, the in-situ measurements of temperature (°C), turbidity (NTU), and specific conductivity (µS/cm) were carried out at the locations. The 42 water samples were filtered onto pre-weighed 1.2 µm Millipore cellulose filters using a vacuum filtration system. The filters were then dried in an oven at 100 °C for 30 min and then reweighed on a high precision balance to determine the weight of TSS (Michaud, 1994, Swift, 2002). 26 pairs of TSS and water spectral

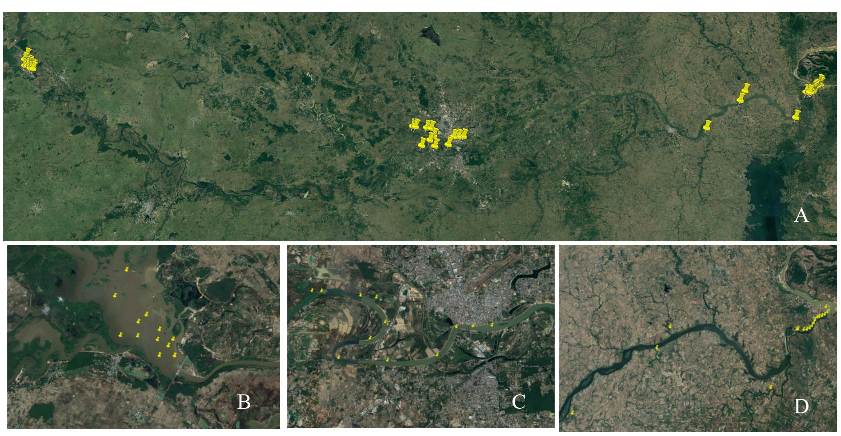


Figure 2: 42 water sampling points along the Mun River (A); 12 water sampling points at Rasrisalai dam (B);12 water sampling points at Ubonrachathani city (C); 18 water sampling points at Pakmun dam (D)

Figure 3: White balance measurement (A); water spectra measurement (B, D); surface water sampling (C)

data were used for model fitting and 16 pairs of measured TSS and estimated TSS from satellite images were used for model validation. TSS values were also transformed using square root transformation to minimize non-linear effects on the fitted models due to TSS saturation. The model for TSS retrieval from green band was used in this study based on the level of coefficients of determination [$R^2 = 0.92$] and the verification results [$R^2 = 0.74$] with statistically strong and significant relations ($p < 0.001$). The model to retrieve temporal TSS variation for different years and months in the Chi-Mun River basin developed in this study. The model equation is given as follows;

$$TSS = 0.0031x - 0.6636$$

where TSS denotes the total suspended sediment measured in mg/L and x is green band represent water spectral reflectance at 490 nm.

5.2 Satellite image processing

In order to quantify estimated TSS from satellite images, three steps were implemented. Firstly, all of the downloaded images were projected to the UTM 48N. Then the images were corrected for atmospheric distortions by converting Digital Numbers (DNs) to radiance and converting the radiance to Top of Atmospheric (ToA) reflectance using FLAASH (Fast Line of sight Atmospheric Analysis of Spectral Hypercubes). The FLAASH module retrieves sensor's gain and offset, as well as geometric information from metadata of those images. After performing FLAASH, the influence of the atmosphere was removed and the images present top of atmosphere spectral reflectance values (Cooley et al., 2002). In the final step, NDWI (Normalised Difference Water Index) was used to identify flooding extent (Gao, 1996). The NDWI images were then converted to binary inundation maps in which the value 1 is used for inundation and 0 for not. The binary inundation maps were then used as masks to generate inundation maps containing reflectance values from the corrected Landsat-5, 8 images.

6. RESULT AND DISCUSSION

The temporal and spatial variations of estimated TSS level in the Chi-Mun River basin from 1992−2017 observed at 15 observation points (3 sites in the Chi River and 12 sites in the Mun River) (Figure4) along with sediment load data measured by RID, Thailand from 2011 -2017 can be described as follows;

6.1 Temporal variations

The TSS level in the Chi-Mun River basin varies seasonally. The level goes down during dry months and rises continuously again in rainy season. The level mostly reaches at peak in July, August, September, and October (Figure 5A, 6); however, the high peak during dry months (January 1993, February 1995, March 1998 and 2006, and April 1993 can be observed (Figure 6A-D). Although the TSS level varies year from year, the seasonal variation of TSS appears constant. The overall TSS level decreases gradually from 1993 to 2015 corresponding to decrease in rainfall in the same period (Figure 6). As the annual rainfall in this basin tends to decrease (Figure 5B), the TSS level in the basin could continue to decline except there are high frequency of extreme rainfall events to elevate the TSS level (Schulz, 2001, Defersha and Melesse, 2012). These suggest changes in amount of rainfall impact on the TSS level in this river basin.

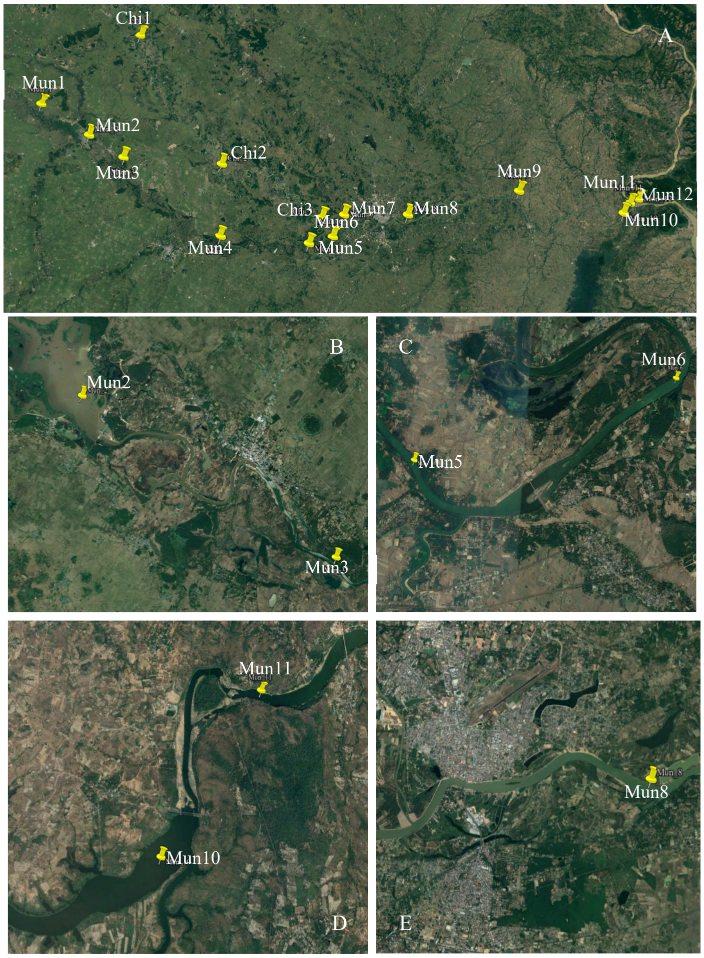
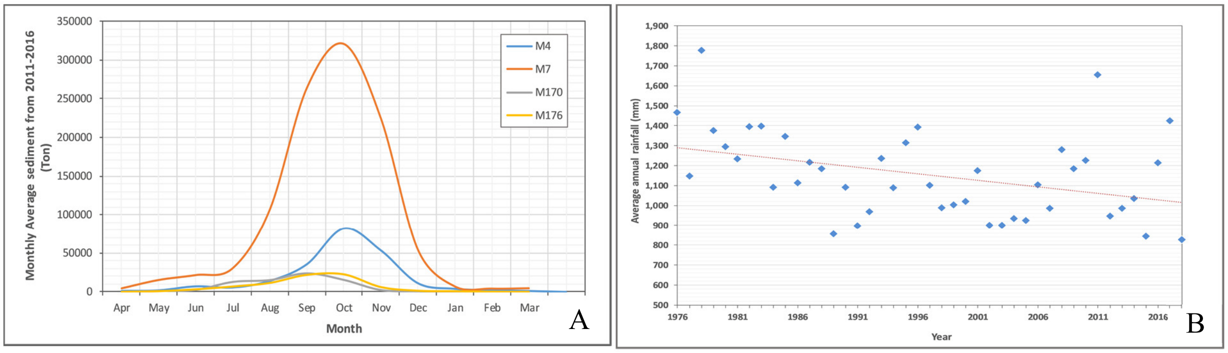


Figure 4: All observation points along the Chi-Mun Rivers (A); observation points upper-lower Rasrisalai dam (B); observation point upper-lower Huana dam (C); observation point upper-lower Pakmun dam (D); observation point near Ubonrachthani city (E)

6.2 Spatial variations

The estimated TSS level in the Chi River was less than the level in the Mun River. The TSS level in the Chi River exhibited low at the upstream site (Chi1) but became higher at downstream site (Chi3) close by the confluence. This spatial pattern of the TSS level in the Chi River remains constant from 1993-2015 which reflects persistent decline in the river flow speed at the confluence. Increase TSS level was mostly found regardless of seasonal change at the sites located near municipalities (Mun8) (Figure 4E) suggesting urban sediments supply to the Mun River (Taylor and Owens, 2009, Walker et al., 1999). In addition, overall spatial distribution of TSS level at the upper dam sites close by Huana dam and Pakmun dam (Mun5, 10) exhibited higher TSS level compared with the lower dam sites (Mun6, 11) (Figure7A-C, I, J) (Figure 8B-C). These indicate that the dams play a key role in retaining suspended sediments resulting in rising of TSS level (Brune, 1953, Kondolf et al., 2014, Kummu and Varis, 2007). However, this spatial pattern cannot be seen at the upper and lower Rasrisalai dam sites (Mun2, 3). On the contrary, the TSS level at this lower dam site (Mun3) near by the Rasrisalai town was greater than its upper site (Mun2)

(Figure 8A), indicating the impact of urban sediment on the TSS level. Although, this pattern can also be found at lower Huana dam site (Mun6) in July and at lower Pakmun site in Mar (Mun11) (Figure 8B, C), the increase TSS level could result from either regular dam draining or the draining



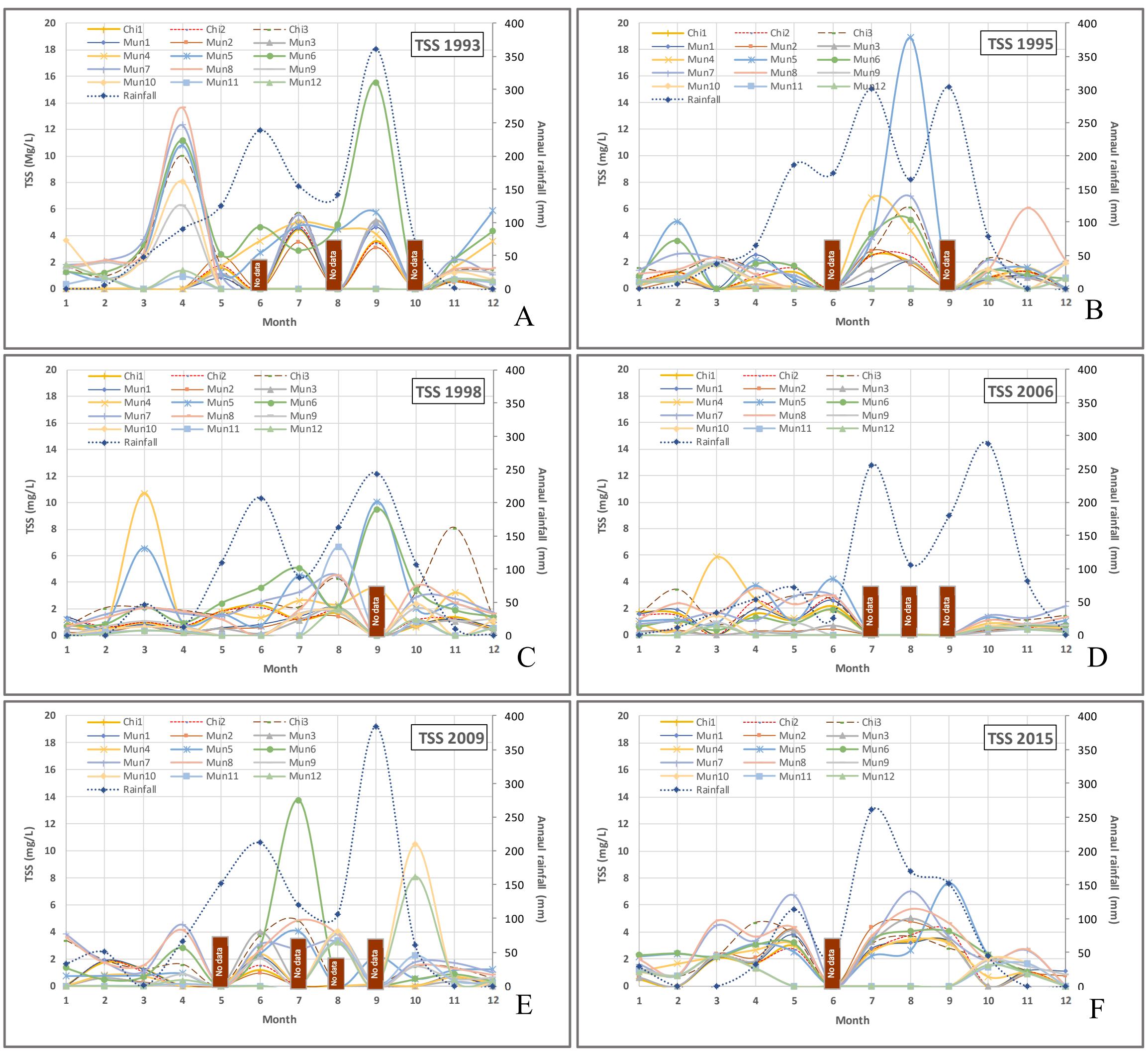


Figure 6: TSS in 1993 (A); TSS in 1995 (B); TSS in 1998 (C); TSS in 2006 (D); TSS in 2009 (E); TSS in 2015 (F)

to prevent overflow during rainy season (Boyd and Gross, 2000) rather than the influence of the urban sediments. Furthermore, given that the location of Mun 11 was close to the Mekong River confluence, this observation point was not only influenced by regular draining but also from suspended sediment transported from the Mekong River (Figure7D-F, K). The trapped suspended sediments can also be seen in lower dam area near by the Mekong River confluence (Figure7G, L) which reflects slow river flow speed in this area.

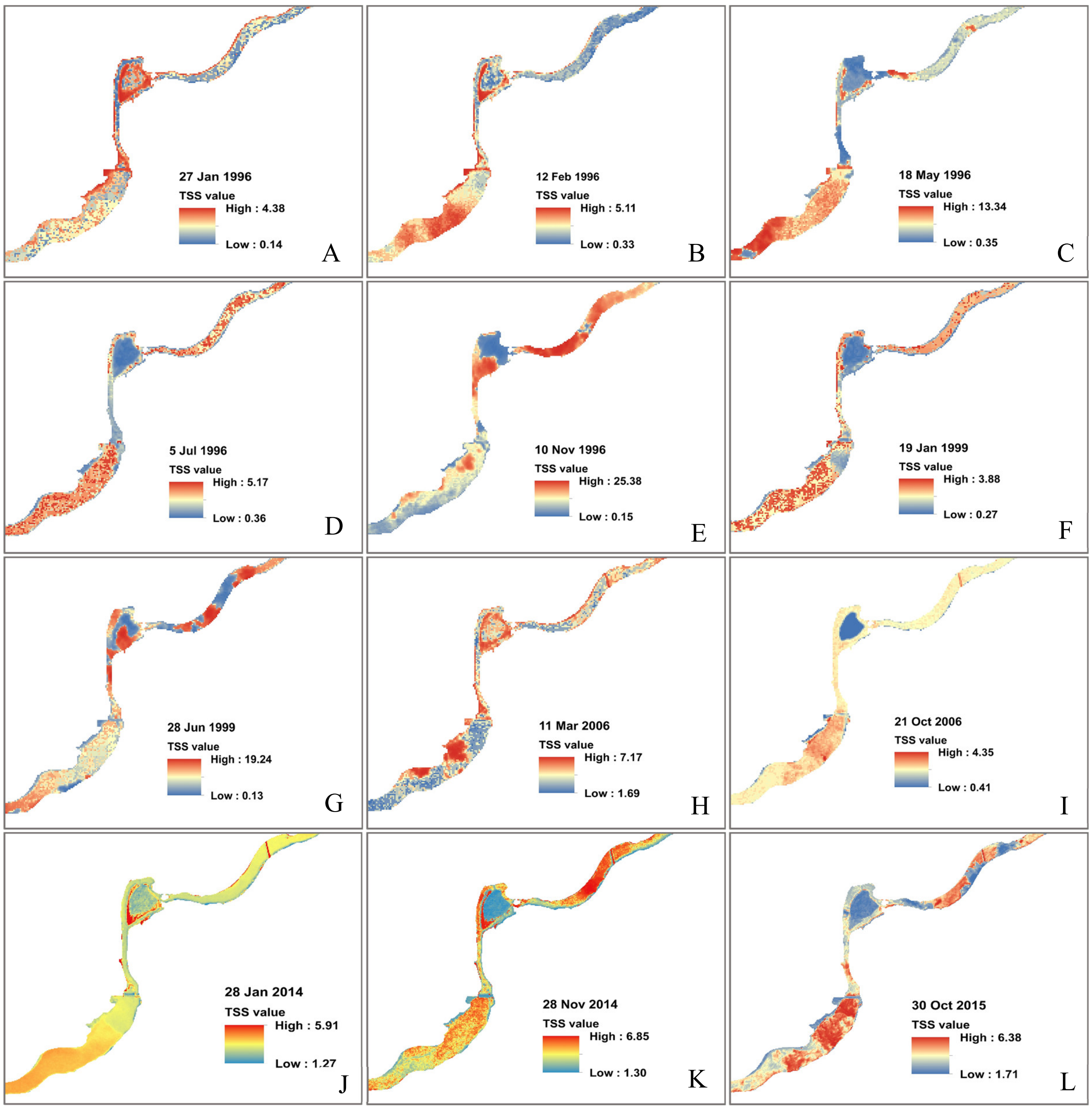


Figure 7: Spatial distribution of TSS level at upper Pakmun dam and lower Pakmun dam from 1996 – 2015 showing high accumulated suspended sediments at the upper dam and lower accumulation at the lower dam (A-C, I, J); the influence of sediments transported from the Mekong River to the lower dam area (D-F, K); trapped suspended sediment at lower dam areas

Figure 8: Comparison of TSS level between upper and lower Rasrisalai dam (A); Comparison of TSS level between upper and lower Huana dam (B); Comparison of TSS level between upper and lower Pakmun dam (C)

7) CONCLUSION

The variations of estimated suspended sediment level in the Chi-Mun River basin are related to seasonal changes. An increase in suspended sediment level was observed in rainy season (May-Oct), while a decrease in suspended sediment level was observed in dry season (Nov-Apr). However, increase in suspended sediment can be found during dry months as a result of urban sediments supply to the river coupled with dam draining. Overall trend of suspended sediment level in this river basin gradually declines corresponding with declining in overall annual precipitation pattern. In addition, the water abstraction along the Mun River also play a key role in trapping of suspended sediment resulting in decrease amount of suspended sediments flow into the Mekong River. Remote sensing technology is a great tool which provides more understanding of suspended sediment dynamics and their response to climate changes and anthropogenic activities in the Chi-Mun River basin. The information obtained from the technology can be used to help establish sediment management strategies in response and mitigation to changes in coastal ecosystem at the Mekong River delta.

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