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SUSPENDED SEDIMENT DYNAMICS CHANGES IN MEKONG RIVER BASIN: POSSIBLE IMPACTS OF DAMS AND CLIMATE CHANGE

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ABSTRACT: This paper evaluates the potential impact of climate change and dams on suspended sediment (SS) dynamics in the Mekong River Basin (MRB). To this end, a distributed process-based sediment transport model was used to examine the potential impact of future climate and dams on suspended sediment dynamics changes in the MRB. Climate scenarios from two GCMs outputs together with effects of 3 existing, 5 under construction and 11 planned dams were considered in the scenario analysis. The simulation results show that the reductions in annual suspended sediment load (SSL) are likely to range from a 20 to 33%, 41 to 62%, and 71 to 81% for existing, under construction, and planned dams respectively in case of no climate change for baseline scenario (1991-2000). Moreover, the reductions on sediment concentration (SSC) are even greater (23% to 78%) due to the potential impact of dams. In contrast, the SSL and SSC shows 40% to 92% increase in the near future (2041-2050) and 28% to 90% in the far future (2090-2099). As the projected climate change impact of sediment varies remarkably between the different climate models, the uncertainty should be taken into account in sediment management. Overall, the changes in SSL and SSC can have a great implication for planned reservoirs and related sediment management.

Keywords: Climate change, Dam, Suspended sediment dynamics, Mekong River Basin

1. INTRODUCTION

The sediment dynamics of a river are sensitive to both a wide range of human activities and climate change within its drainage basin. These factors could influence sediment mobilization and transfer through action like clearing land, agricultural development, mineral extraction, urbanization, dam and reservoir construction and soil conservation and sediment control programs [1]. Accelerated erosion due to human-induced environmental alterations at the global scale is causing an increase in geomorphic process activity and sediment fluxes in many basins in the world [2], [3]. It is also becoming increasingly obvious that sediment loads in the world's river, particularly in large rivers have been impacted by human activities.

A recent study of 145 major rivers with longer-term records of annual sediment loads and runoff showed that around 50% of river records demonstrated a statistically significant upward or downward trend [4]. The majority of these rivers demonstrated declining sediment loads due to dams and other river control structures trapping sediment. The variables such as climate, soil type, land cover, topography and anthropogenic activities influences soil erosion and sediment transport in the watershed [5], [6], [7].

The main objective of this study is to evaluate the potential impact of anticipated future climate and dam constructions on the suspended sediment (SS) dynamics under near future (2041-2050) and far future (2091-2099) scenarios. The magnitude of the change is demonstrated with different scenarios. In this work, the past suspended sediment load (SSL) and suspended sediment concentration (SSC) in the MRB were simulated to the conservations from 1991 to 2000. Using the calibrated model parameters, the sediment dynamics processes were then projected for the 2040s and 2090s, considering the expected changes in two factors; climate and dams (existing, under construction and planned).

2. METHODOLOGY

2.1 Target River Basin

The present study focused on the MRB, which covers an area of approximately 795,000 km^2 (Fig. 1). The most dominant land use in the basin consists of approximately is forest with 33%. Among major rivers of the world, the Mekong ranks 12th in length (4880 km), and 22nd in catchment area. The wet season lasts from May to October when the average rainfall around 80-90% of the annual total. The dry season period starts from November and lasts until

April. The minimum annual rainfall is 1000 mm/year (NE of Thailand) and the maximum is 4000 mm/year (West of Vietnam).

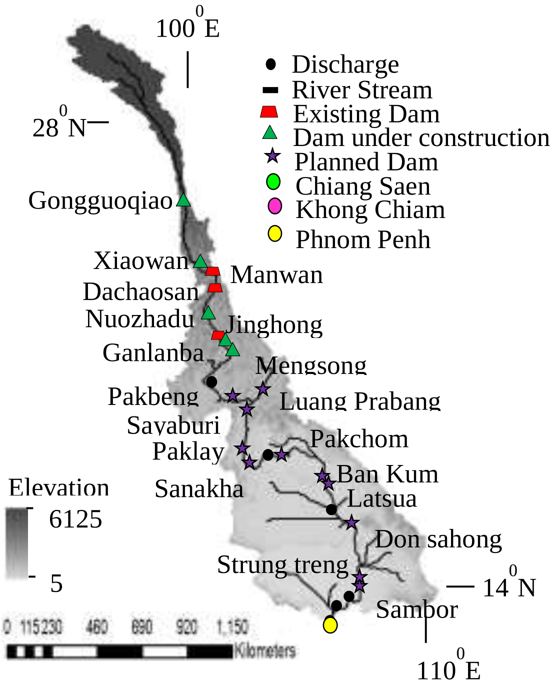

Fig.1 Map of the Mekong River Basin with existing, under construction and planned dams.

The MRB is populated with approximately 60 million people and is considered to be one of the most culturally diverse regions of the world. Agriculture, fishing and forestry provide employment for approximately 85% of the basin's residents. In this basin, acrisols were found the dominant soil type (59%), which are tropical soils that have a high clay accumulation in a horizon and are extremely weathered and leached. Their characteristics include low fertility and high susceptibility to erosion if used for arable cultivation [8]. The rest of the areas are mixtures of deciduous and evergreen covers as well as woodland and shrubland with some undisturbed forest land.

2.2 Distributed Sediment Model

The important processes of sediment dynamics were modelled and integrated with a process-based distributed hydrological model (DHM) [9]. It solves the continuity, momentum and energy equations using two modules; hillslope and river routing. The integrated distributed model uses a basin subdivision scheme, a sub grid parameterization scheme, a physically based hillslope hydrological simulation and kinematic wave flow routing in river network [10]. In sediment model, sediment dynamics on hillslope and rivers was separately modelled and systematically linked each other. Hydrological and sediment processes are calculated on daily time-step. Further details can be described by [9] for hydrological model and for sediment model in [11]. Furthermore, the parameters distributed sediment model were calibrated for baseline scenario in previous study.

2.3 Dam Scenarios

The location of reservoirs [12] in the mainstream of the MRB are presented in Fig. 1. Four different scenarios were used for investigating the effects of the dam which are D1: baseline (without dam), D2: three existing dams, D3: scenario D2 and 5 construction dams and D4: scenario D3 and 11 planned dams, Table 1.

Eleven dams are proposed (nine in Lao PDR and two in Cambodia) in the Lower Mekong Basin (LMB) and five dams are under construction or designed in Upper Mekong Basin (UMB) in addition to the three existing ones (Xiaowan, Manwan and Dachaosan). The cumulative storage of all the existing and planned reservoirs was obtained from Mekong River Commission [12] and by [13]. The dam release at each dam (existing, construction and planned) was assumed equal with inflow, assumed no water withdrawal. Additionally, the trap efficiency (TE) equations by [14] were used to approximate individual reservoir sedimentation.

Table 1 Scenarios to examine dams on suspended sediment dynamics in the Mekong River Basin. CPO used the observed precipitation in the past, while CPM used the model output from GCMs for precipitation

Dam Scenario (D)		Past Observation (CPO)	Past Model (CPM)
Baseline (no dam)	D1	D1-CPO	D1-CPM
3 dams (existing)	D2	D2-CPO	-
8 dams (D2 + under construction)	D3	D3-CPO	-
19 dams (D3 + planned)	D4	D4-CPO	D4-CPM

2.4 Climate Change Scenario

For the climate impact assessment, the distributed sediment model was driven with outputs of two biases corrected datasets. The first Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP), RCP 2.6 and RCP 8.5. ISI-MIP is designed to synthesize impact projections in the agriculture, water, biome, health, and infrastructure sectors at different levels of global warming. The ISI-MIP datasets comprises bias-corrected daily. The GCMs data were archived from MIROC-ESM-CHEM and HadGEM2-ES. Later the following abbreviations were used by for scenarios produces by these models: MIROC and HadGEM2. Moreover, these two GCMs were selected on the basis of their performance in the simulation of precipitation in the 20th century in the Southeast Asia region [15], [16]. These two models were selected based on the availability of daily data and all the representative concentration pathway (RCP) scenarios.

The RCPs scenarios are based on four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC in its fifth Assessment Report (AR5). The four RCPs are named after a possible range of radiative forcing values in the year 2100 (+2.6, +4.5, +6.0 and +8.5 W/m^2 respectively). The different pathways are coded according to their radiative forcing at the end of the 21st century as RCP2.6, RCP4.5, RCP6.0, to RCP8.5. Climate scenarios were downscaled to a grid resolution of 0.5 degrees and bias-corrected by the ISI-MIP project using a trend-preserving bias-correction method with the WATCH reanalysis data [17].

Table 2 Scenarios to examine climate change on suspended sediment dynamics in the Mekong River Basin

Dam Scenario	(D)	Near Future Climate (CN) RCP 2.6	Near Future Climate (CN) RCP 8.5	Far Future Climate (CF) RCP 2.6	Far Future Climate (CF) RCP 8.5
Baseline (no dam)	D1	D1-CN 2.6	D1-CN 8.5	D1-CF 2.6	D1-CF 8.5
19 dams (D3 + planned)	D4	D4-CN 2.6	D4-CN 8.5	D4-CF 2.6	D4-CF 8.5

In this study, climate scenarios were divided into three decades which are past climate observation 1990-2000 (CPO) and past climate measured from GCMs model (CPM), near future climate 2041-2050 (CN) and far future climate 2090-2099 (CF). Two GCM model output was selected (MIROC and HadGem) and two RCPs (RCP2.6 and 8.5) were used for each model output. These climate scenarios were combined with dam scenario (Table 2).

3. RESULTS AND DISCUSSION

3.1 Impact of dams on river discharge, SSL and SSC

The average annual river discharge remains same in each dam scenario because no water withdrawal was assumed in each scenario (Fig. 2a). The average annual SSL shows changes with dam scenario at three observation station, Chiang Sean, Khong Chiam and Phnom Penh (Fig. 2b). It shows decreasing trends in scenario D2 to D3 and D4. However, the SSL at each station shows a slight change from scenario D2.

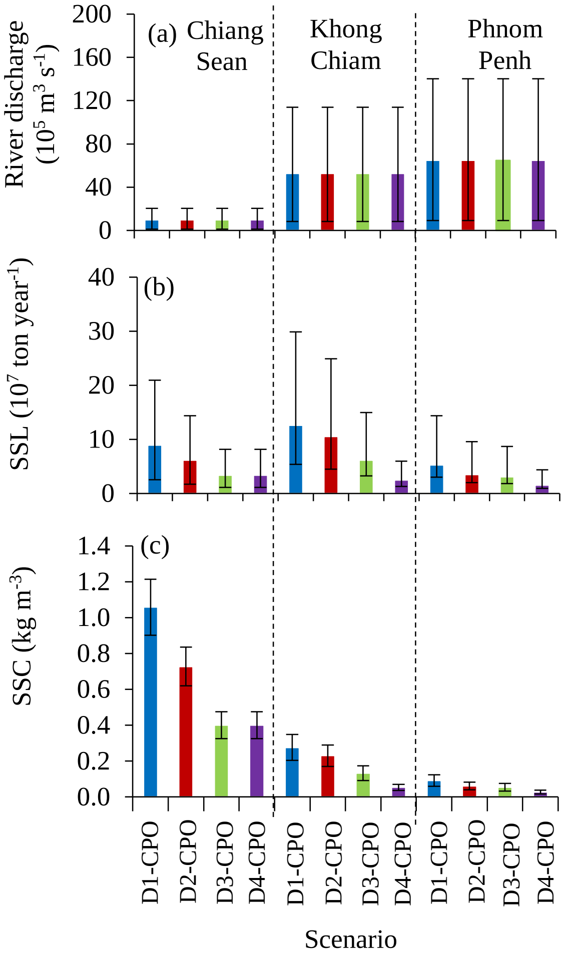

Fig. 2 Average annual (a) river discharge, (b) suspended sediment load, and (c) suspended sediment concentration at Chiang Sean, Khong Chiam and Phnom Penh stations for dam scenario. Error bars show the minimum and maximum value of an average annual river discharge (a) and SSL (b) and standard deviation of average annual SSC (c). Note: See Table 1 for scenario code

The result shows that the existing dam in the upper part of MRB does not show much effect to the downstream SSL. But, obviously, the increasing number of dams affected the amount of SSL (scenario D3 and D4). The reduction in SSL is large in upstream dams and becomes small as it moves downstream, which may be due to variations in the rate of change of rainfall and soil loss from sub basin to sub basin.

Figure 2c shows the average annual SSC with similar trend with SSL which are decreasing from D1 to D4. This implies that the impact of dams on the SSC is same as SSL because of the deposition losses, reducing the SSL as it transported downstream, these will also contribute to the reduction in SSC. In addition, the SSC profile shows the decreasing trend from upstream to the downstream.

Overall, an increasing number of dams are linearly decreased with SSL and SSC. Changes in SSL and SSC in the future can have implications for planned reservoirs and related sediment management. For instance, decreasing SSL will frequently bring obvious benefits in terms of reduced sedimentation and siltation. It is important to recognize that there can also be a negative impacts associated with reduced nutrient inputs to lakes, wetlands, floodplains, delta and coastal areas, resulting in major ecosystem disturbances [18], [19].

3.2 Impact of climate change on river discharge, SSL and SSC

The simulated discharge driven by bias-corrected climate model outputs in the period 1991-2000 (D1-CPM) was compared with the observed one. The simulated and observed discharge agrees well for both driving climate models due to the bias-correction of climate model outputs.

Figure 3a and 4a shows the average annual river discharge using output models MIROC and HadGem2 respectively. In general, river discharge on far future (2090-2099) is higher than near future (2041-2050) due to increasing precipitation. However, both model outputs show the same increasing trend from the past in term of river discharge.

The average SSL shows a decreased trend with increasing number of dams (from D1 to D4) for all climate scenarios (Fig. 3b and 4b). The average annual SSL changes ranges from 44% increased at Phnom Penh respectively from near future climate (2041-2050) to far future (2090-2099) for scenario without a dam. The variation in simulated SSL between the climates models used in this study is significant, as it indicates a high degree of uncertainty in the direction of hydrological change due to climate change. As [20] indicate that the changes of sediment yield and discharge in response to climate change do not always happen in the same direction in the Song Cau watershed in Northern Vietnam. Error bars in Fig. 3a, b and 4a, b shows value of maximum and minimum average annual river discharge and SSL.

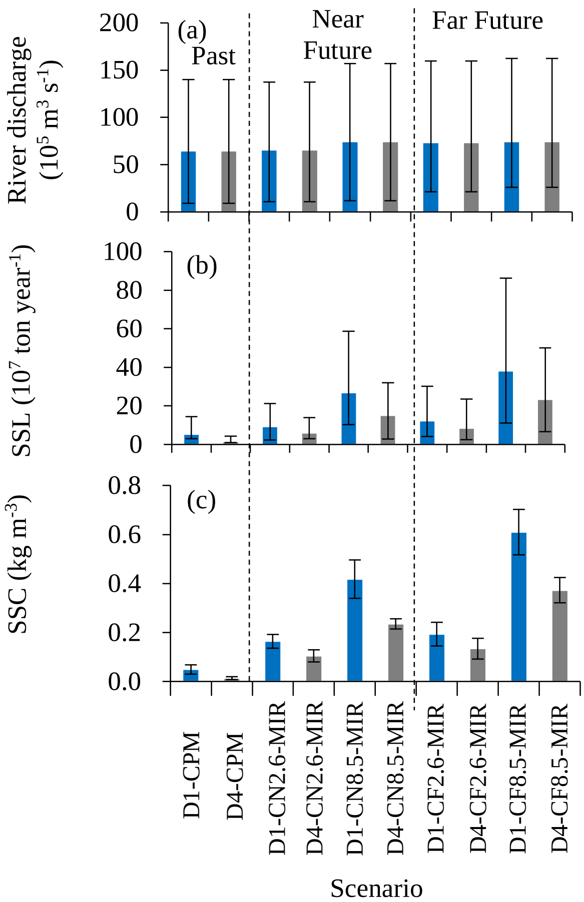

Fig. 3. Average annual of (a) river discharge, (b) suspended sediment load, and (c) suspended sediment concentration at Phnom Penh station using MIROC output. Error bars show the minimum and maximum value of an average annual river discharge (a) and SSL (b) and standard deviation of average annual SSC (c). Note: See Table 2 for scenario code.

Figure 3c and 4c show the average of simulated annual SSC in near future and far future under various MIROC and HadGEM2, climate models. A significant change in average annual SSC Phnom Penh (Fig. 3c and 4c) was confirmed. A reduction in SSC is predicted to occur from 1% to 50%, depending on the scenarios and locations. Moreover, the results show that MIROC estimated higher SSL and SSC in the future than HadGEM2. This is mainly due to higher precipitation projections by MIROC than HadGEM2. However, both model outputs showed the same trends on SSL and SSC.

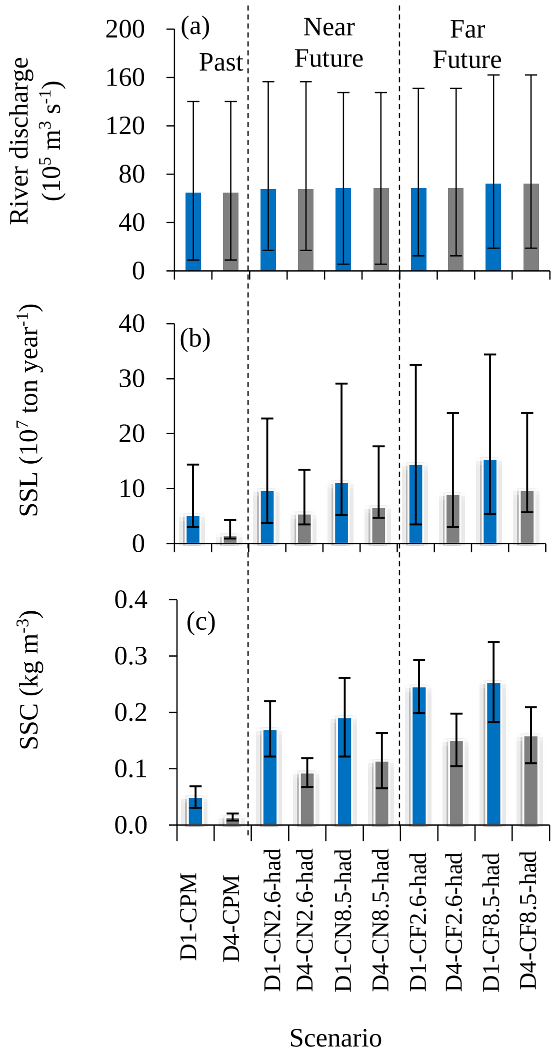

Fig. 4. Average annual of (a) river discharge, (b) suspended sediment load, and (c) suspended sediment concentration at Phnom Penh station using HadGEM2 output. Error bars show the minimum and maximum value of an average annual river discharge (a) and SSL (b) and standard deviation of average annual SSC (c). Note: See Table 2 for scenario code.

4. CONCLUSIONS

This study assessed the impact of dams and climate change on SSL and SSC in the MRB. In this work, scenarios considering climate change and dam construction were applied for the examination on their potential effects on SSL and SSC. A distributed process-based model is used to simulate the present situation and future changes in sediment load and concentration in the target basin. Distributed models' parameters of river discharge and sediment were calibrated and applied to simulate future changes in river discharge, SSL and SSC.

In general, SSL and SSC values decreased from upstream to downstream due to increasing number of dams. Higher river discharge and SSL are expected when the heavy rainfall takes place. The climate change showed higher impact on sediment than on river discharge, and those changes do not necessary happen in the same direction. The results indicate that large uncertainties exist in all projected future hydrological variables (i.e., rainfall, discharge and sediment) due to differences in the climate model projections.

The outcomes of this study may be helpful to development planners, decision makers and other stakeholders when planning and implementing appropriate basin-wide sediment management strategies. Moreover, the results may support relevant sectors to reassess the design, operation and sedimentation of dams.

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