ANALYSIS OF LAND USE LAND COVERAGE DYNAMICS AND ITS EFFECTS ON RAINFALL-RUNOFF AND RUNOFF-SEDIMENT PATTERNS IN YOM RIVER BASIN THAILAND

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ABSTRACT

This research studies the land use dynamics and its effects on rainfall-runoff and runoff-sediment relationships in Yom river basin of Thailand. The study compares land use land coverage change (LULCC), rainfall-runoff pattern, and sediment load in the main river course from 1980s to 1990s and to 2014. A land use map updated from different periods (Land Development Department, Thailand) in combination with digital elevation model (DEM) and satellite imageries have been carried out as inputs for land use change coverage analysis. Double mass curve with trend curve analysis is employed to evaluate the effects of LULCC on rainfall-runoff and runoff-sediment yield relationships. The results indicate that from 1990 to 2014, many forests in Yom river basin have been significantly transformed into farmland and irrigation area, especially in high-slope locations relatively further away from the main river course. This change of land use pattern has consecutively altered the rainfall-runoff and runoff-sediment relationships, and lead to more pronounced slope of trend curve (STC) of annual rainfall-runoff and runoff-sediment mass curves in 1990s compared to 2000s, implying that more soil and water loss yield in 2000s. One can logically suggest that the runoff-sediment load obtained during 1990s is higher than 2000s with similar rainfall/runoff, which can further be explained by the historic landuse dynamics. With the new water allocation scheme for flood risk reduction in the lower Chaophraya river basin, agricultural practices have spatio-temporally changed and parts of Yom river basin have been used for flood retention areas, significant alteration in rainfall-runoff and runoff-sediment patterns has been observed (i.e., in Bangrakam and Kongkrailart Districts). Continuous reduction of forest fraction results in soil loss, landslide, river bank erosion, and flood occurrence results in a more degrading river water quality and potential decrease in river capacity for flood protection, all involved stakeholder such as local authorities, communities, farmers, and policy makers should pay attention to apply appropriate land use and watershed management and flood risk reduction practices.

Keywords: Rainfall-runoff, runoff-sediment, land use dynamics, water balance, sediment load, double mass curve

1. INTRODUCTION

In 2011, Thailand received global attention from its worst flood disaster in five decades. The Chao Phraya river basin is one of the areas severely hit by the flood, starting from July in the Northern Chao Phraya river basin to October when the lower Chao Phraya river basin and Bangkok are mainly affected. The socio-economical damages from this flood are estimated at 45.7 billion USD by the World Bank, especially to the industrial sector, which is 10 times higher than the loss due to previous major flooding. To make the story worse, the water situation in the basin is soon shortage afterwards during the following dry season (i.e., November 2011 to April 2012). The Chao Phraya river basin is located in the heart of Thailand, covers roughly 30% of the country's land surface (i.e., 160,000 km^2), and is considered the largest river basin in the country. The hydrodynamic of rainfall and flow characteristics as well as quantities and intensities of the rainfall and flow in upper Chao Phraya river basin are in fact controlling the total inflow discharging directly to the lower Chao Phraya and draining into the Gulf of Thailand respectively. Studies on flood controlling of the Greater Chao Phraya basin, therefore, have always mainly focused on flow characteristics in the upper basin (i.e., Ping, Wang, Yom, and Nan river basins) upstream of C2 gauging station located in Nakorn Sawan province of Thailand. Yom river basin, located in the upper part of the Greater Chao Phraya river basin, has been facing flood and drought risk management problem as it is considered the only unregulated basin in Thailand. The basin has experienced a great deal of deforestation, water resources development, urbanization, and industrial development during the past three decades, following the similar global trend that this area is currently used as cropland instead of natural vegetation such as forests and grasslands (Goldewijk 2001; Ramnkutty and Foley 1998). Such clearing of natural vegetation by humans occurring rapidly over recent decades surely affects the hydrological and ecological characteristics at the watershed-level, which can lead to potentially significant changes in runoff and sediment loading.

2. MATERIALS AND METHODS

2.1 Study area

Yom river basin (**Figure 1**) is 22,715.5 km_2 and located in the Northern part of Thailand, between 15°51′N–19°24′N latitude and 99°13′E – 100°40′E longitude. The upper part of the basin is mountainous region with several narrow cross-sections of the main river downstream. The lower part of the basin locates a major city of Sukhothai province with high urbanization rate. Sukhothai province experiences inundation due to overbank flow almost every year.

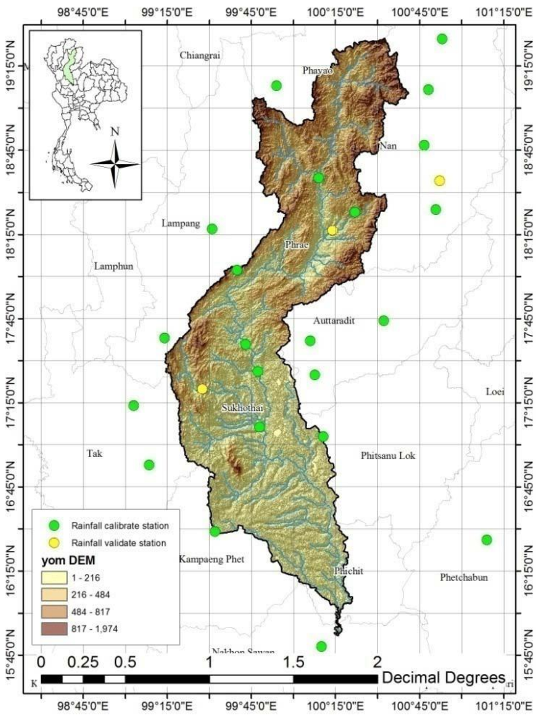

Figure 1. Study area (Yom river basin).

2.2 Methods

In this study, double mass curve analysis has been employed to express the spatial distribution of land use pattern based on slope gradient and the distance to river. The relationships of rainfall-runoff and runoff-sediment can be identified by double mass curve. The theory behind double-mass curve analysis is that if values for two variables change proportionally over time, a graph of the accumulation of one quantity against the accumulation of another during the same period of time should be plotted as a straight line (Wigbout 1973; Kalra 1989). In order to compare the change of relationships of different periods, linear trend curve for each double mass curve can be constructed and the slope of trend curve (STC) can be used to reflect the increasing runoff speed (or sediment concentration) based on rainfall (or runoff). If the STC of rainfall-runoff mass curve is higher in period A than period B, it implies that the land use pattern is somewhat changed and producing more runoff.

2.3 DEM and land use data

DEM dataset with resolution of 90 m obtained from the USGS (**Figure 2**) are used to extract the topographic information needed for hydrological modeling, such as slope and channel width. It is projected into the UTM_WGS84_47 coordinate system before proceeding. Land use pattern for this study from Years 2000 and 2006 (**Figure 3**) are collected from the Land Development Department (LDD) with 4 land use categories (to match with SWAT landuse categories for future work) as shown in **Table 1**.

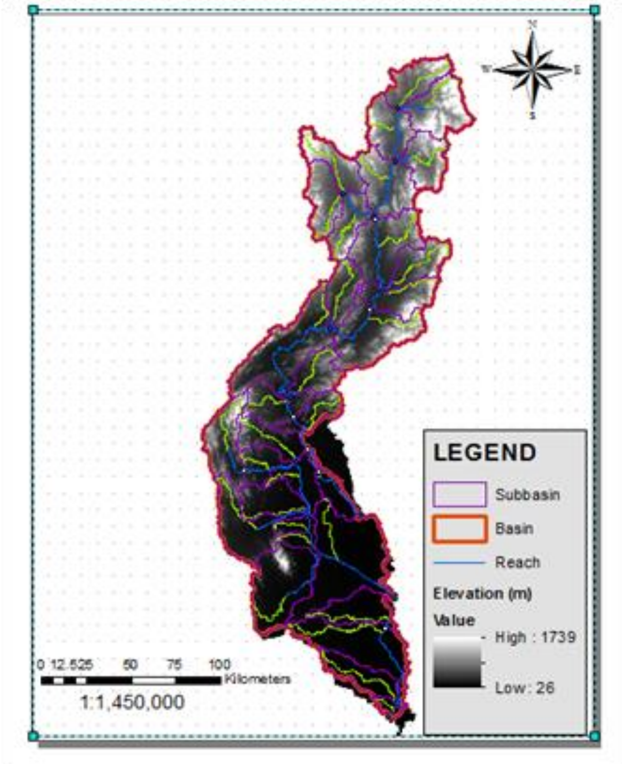

Figure 2. DEM of Yom river basin.

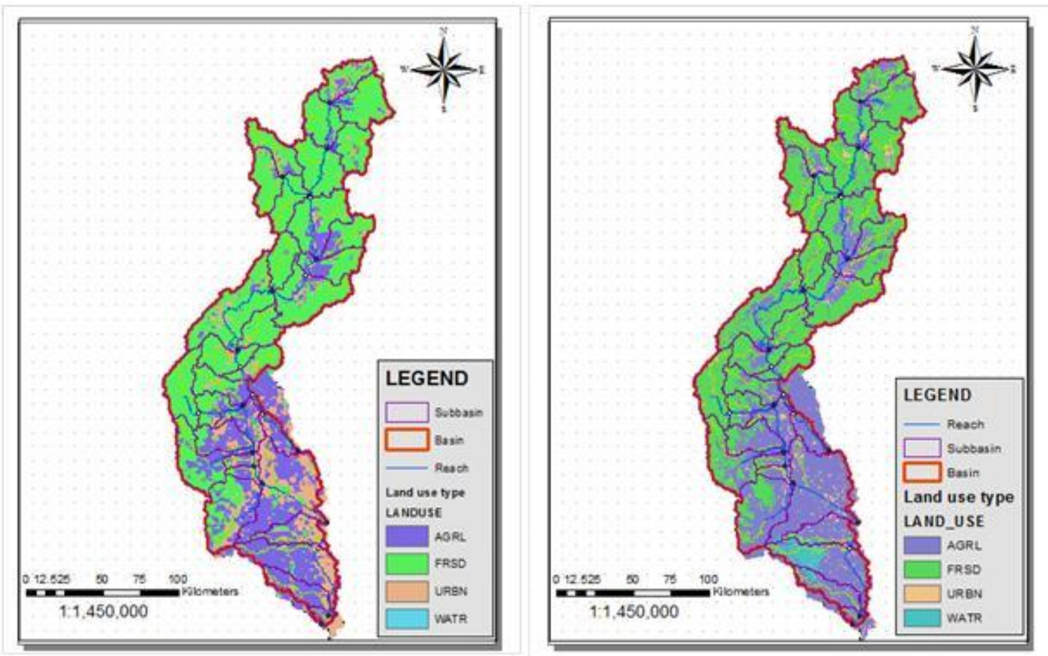

Figure 3. Land use pattern of Yom river basin in year 2000 (left) and 2006 (right).

Table 1. Caption heading for a table should be placed at the top of the table and within table width.

Land use type	**LU 2000**		**LU 2006**		**Change**	
	Area (ha)	**(%)**	**Area (ha)**	**(%)**	**Area (ha)**	**(%)**
Agriculture, AGRL	586,455.6	25.8	915,697.1	40.3	329241.6	+14.4
Deciduous Forest, FRSD	1,347,367.8	59.3	1,213,118.1	53.4	-134250	-5.9
Urban, URBN	336,628.1	14.8	825,34.1	3.6	-254094	-11.2
Water, WATR	1,099.6	0.05	60,201.8	2.6	59102.2	+2.6

2.4 Meteorological and hydrological data

Meteorological and hydrological data at Y.1C, Y.6, Y.16 and Y.17 (upstream to downstream stations) are employed in this study. The location of streamflow and sediment stations are currently presented in **Figure 4**.

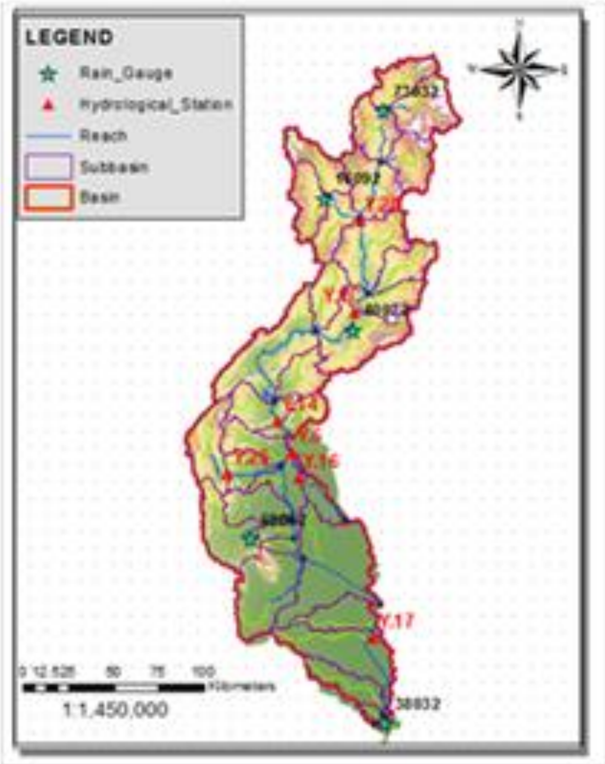

Figure 4. Hydro-meteorological stations in Yom river basin.

3. RESULTS AND DISCUSSION

3.1 Rainfall-runoff-sediment relationship (year 2000-2006)

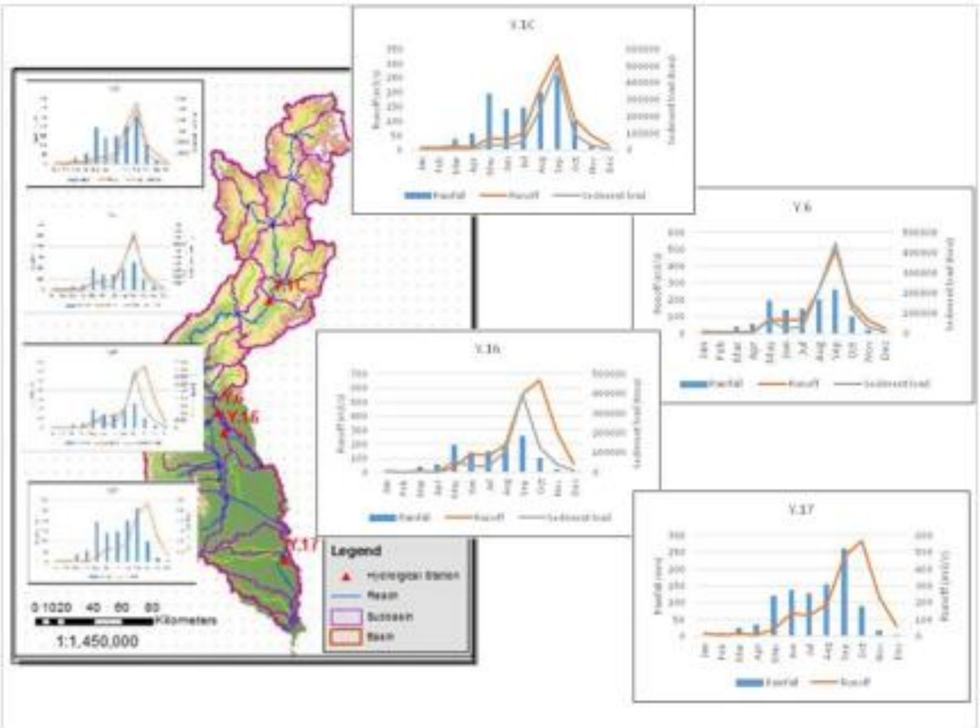

Figure 5. Average monthly rainfall-runoff-sediment data at stations Y.1C, Y.6, Y.16, and Y.17.

Areal average precipitation from 5 rain gauges scattered around Yom river basin is calculated with its corresponding area is calculated by using *Thiessen Polygon Method.* Monthly areal average rainfall data from year 2000-2006 are plotted against monthly runoff and monthly sediment data set collected from runoff stations along the main Yom river course. Due to limitation in sediment data collection in Yom river's tributaries, runoff and sediment data from tributaries of Yom river are not included in our analyses. The rainfall-runoff-sediment relationships are presenting in **Figure 5**. With the annual precipitation of 1,174.67 mm/year, the annual runoff at the upstream of watershed (Y.1C) is 890 m^3/s. Runoff intensity increases from mid-stream to downsteam as can be observed from Y.6, Y16, and Y17 stations (1,324 m^3/s, 1,854 m^3/s, and 2,076 m^3/s, respectively). The suspended sediment load detected along Yom river course also increased with runoff from upstream to downstream of the basin, i.e., 813,142 tons/year at Y6, 948,879 tons/year at Y16, and 975,178 tons/year at Y17, respectively.

The results indicate that rainfall-water discharge (i.e., runoff)-suspended sediment load are actually correlated for all stations in the study area, both upstream and downstream of the basin. Suspended sediment in the river is also reasonal dependent as higher suspended sediment concentrations are observed with increasing rainfall and runoff in rainy season (i.e., May-October). On the other hand, very low rainfall in the area results in lower runoff along Yom river and therefore obviously leads to a lower suspended sediment load in the river during dry period (i.e., Nov-April). From year 2000-2006, the maximum rainfall occurs in September as well as the peak runoff and sediment in every station in Yom river basin, except at Y16 and Y17 stations downstream. For both downstream stations, the peak runoff occurs in October, while the maximum rainfall is observed in September. Shifting of the peak runoff at downstream stations is perhaps due to changes of landuse pattern and the expansion of irrigation projects in the lower part of Yom river basin (as can be seen in **Figure 3**).

3.2 Changes of land use pattern from 2000 to 2006

To assess any significant changes of land use patterns in Yom river basin, 2 versions of land use map are employed. The year 2000 and 2006 landuse maps are overlaid and compared using the aids of spatial tools in ArcGIS software. **Table 1** presents the area difference in land use categories in year 2000 and 2006. From **Table 1**, Agriculture land and water body increase by 329,241.6 ha and 59,102.2 ha in year 2006, respectively. While agricultural area and water body increase, significant deforestation occurs. It can be observed that in year 2006, fraction of forest covered land and residential area are decreased by 134,250 ha and 254,094 ha, respectively. In conclusion, significant deforestation occurs in Yom river basin with increase in residential and agricultural area in 2006 compared to the land use pattern observed in 2000.

In this study, we aim to focus more quantitatively on land use patterns change from year 2000 to 2006 by extracting slope gradient and distances to river from DEM as well as their classification maps for land use pattern analysis. Versus slope gradient and distance to river, the accumulated area percentage curves of land use in 2000 and 2006 are shown in **Figure 7**. The total percentage of land use in the figure is summarized to 100%, but water body type (WATR) is omitted as it is only accounted for small percentage. It can be seen that land use pattern has undergone obvious transformation in the seven years. The area of forest is more than that of agricultural land (farmland) in 2000 while fractions of agricultural and urban area fall under at fairly low percentages (FRSD 40.56%, AGRL 31,62%, URBN 27.65%). While the majority of the land use in the study area is dominant by agricultural activities in 2006 (FRSD 32.6%, AGRL 60.2%, URBN 6.3%).

The distribution characteristic of land use based on distance to river is different from 2000 to 2006 as well. The distribution area of urban land is higher than those of forest and agriculture within the distance of 1,600 m to river in 2000. This trend is not observed in 2006, implying that some forest far away from the river has been changed into agricultural area in 6 years, especially the land located further than 1,600 m from the river. This is perhaps due to the extension of better irrigation system developed by the Royal Irrigation Department (RID) and other local authorities.

3.3 Effects of land use pattern on rainfall-runoff and runoff-sediment relationships

In this study, we aim to focus more quantitatively on land use patterns change from year 2000 to 2006 by extracting factors affecting runoff include land use, vegetation, soil type, topography, rainfall, drainage network patterns, and so on, among which land use is the main factor to affect rainfall-runoff relationship. The overall impact of various land use on hydrology depends on the combined effect of differences in interception, transpiration and infiltration capacities (**Wilk 2002**). And therefore runoff, as a process in hydrologic cycle, is also affected by land use pattern as well.

The relationships between rainfall and runoff are evaluated in the two periods (from 1999 to 2002, from 2003 to 2006). Annual precipitation is calculated as the areal average precipitation (by Thiessen Polygon Method).

It is accumulated and compared to the cumulative annual runoff at upstream station Y.1C using a double mass curve. The linear trend curves and its regression equations are generated and further analyzed.

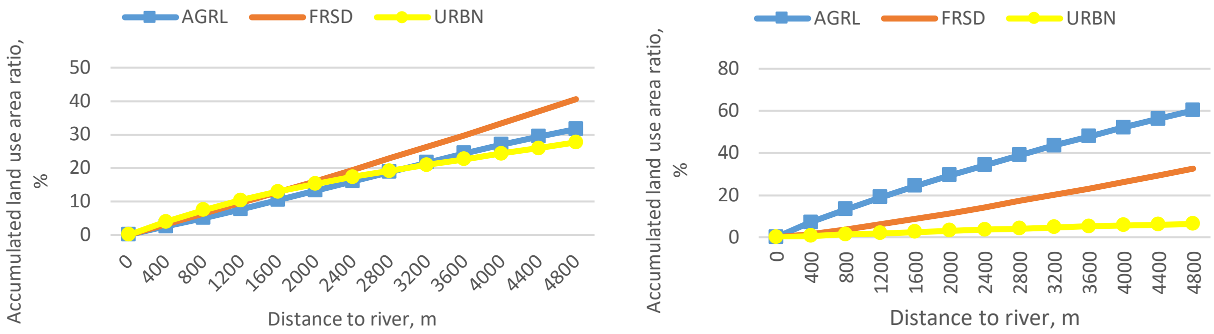

Figure 7. Accumulated percentage land use area versus distance to river at different time period in Yom river basin (left: year 2000; right: year 2006) (AGRL: agricultural land; FRSD: forest; URBN: urban/residential).

Figures 8 and 9 illustrate annual double mass curves and its trend curves of rainfall-runoff and runoff-sediment in the study area at station Y1C (i.e., the upstream station). The goodness of fit for every regression line is obviously very good (***R_2*** > 0.9). The annual STC from 1999-2002 is a little bit higher than that of 2003-2006, indicating that the annual cumulative runoff increased more rapidly, and more runoff yield is therefore observed with similar rainfall. For runoff-sediment relationships in **Figure 9**, STC is higher in the recent years (2003-2006), suggesting that the more sediment loading at station Y1C is expected at the similar runoff. In conclusion, less runoff with high sediment loading capacity is expected in the upstream area where the majority of land use is dominated by extended agricultural land, especially in the land near the main river course with more contribution to runoff than that far away from the river. Land use pattern change comparison between early years (2000) and more recent years (2006) yield significant deforestation is observed in Yom river basin, especially in the downstream area of the basin. Therefore, change in STC between early years and recent condition is consistent with the land use pattern change of the basin. As for the different months, the hydrologic response to rainfall is expected to be due to several factors, including vegetation and rainfall dynamic.

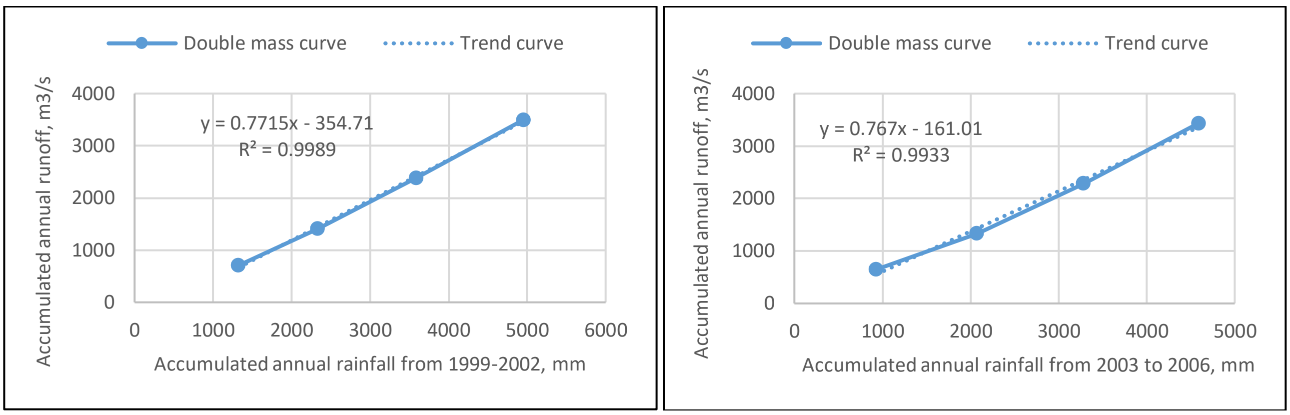

Figure 8. Double mass curve of annual rainfall data and runoff comparison at upstream station Y.1C between year 1999-2002 (left) and year 2003-2006 (right).

Not only the rainfall-runoff and runoff-sediment relationships are explored at single station, but the spatial characteristics of rainfall-runoff and runoff-sediment relationships is also evaluated. The annual precipitation at each runoff-sediment station from the nearest rainfall station is calculated individually. Annual precipitation at each corresponding rain gauge is calculated, accumulated, and compared to the cumulative annual runoff using a double mass curve. The linear trend curves and its regression equations are also determined for further analysis. The relationships between rainfall and runoff are evaluated in upstream, midstream, and downstream from 2000 to 2006. From the regression analysis with R_2>0.9, STC of annual rainfall-runoff mass curve at downstream station Y.17 is higher than the upstream Y.1C, Y.6, and Y.16 for both periods, indicating that the annual cumulative runoff increases more rapidly in the downstream area of the basin compared to the runoff characteristics upstream with similar rainfall.

With increasing runoff from upstream to downstream of Yom river basin, it is expected to see the similar trend in suspended sediment loading along the river from upstream to downstream as well. Figure 11 presents double mass curve analysis of annual runoff and sediment loading at stations Y1C, Y6, and Y16 stations. Y17 station is the most downstream station in the basin, however, its sediment data is not completely collected. Therefore, the sediment loading data from station Y16 is considered the most downstream one in this analysis. Based on the regression coefficient, STC(s) of the annual runoff – sediment mass curve at midstream and downstream stations Y6 and Y16 are relatively higher than the upstream Y.1C station from 2000-2006 periods, indicating that the annual cumulative sediment increases more rapidly in the downstream area of the basin compared to the upstream with similar runoff characteristics.

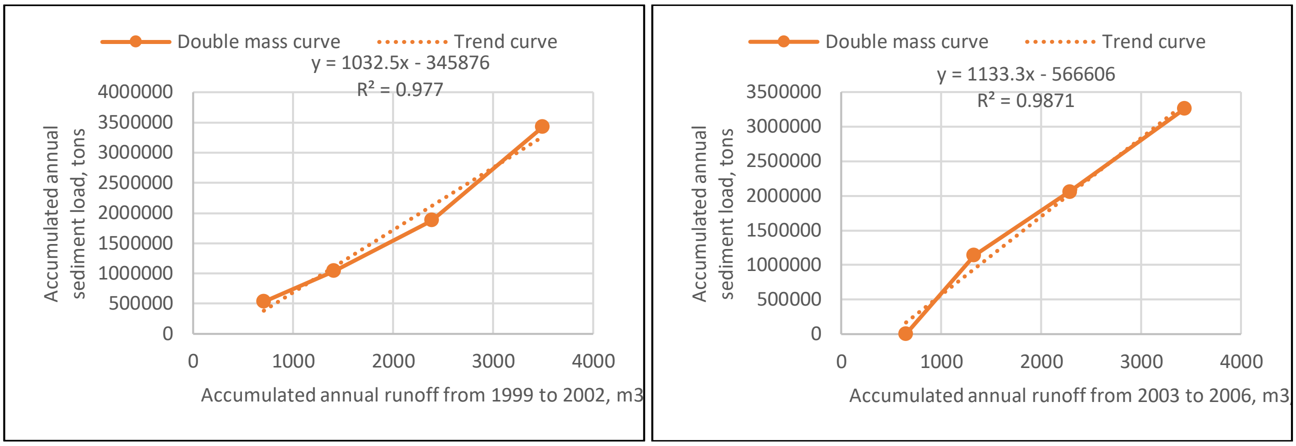

Figure 9. Double mass curve of annual runoff and sediment load comparison at upstream station Y.1C between year 1999-2002 (left) and year 2003-2006 (right).

4. CONCLUSIONS

This research studies the land use dynamics and its effects on rainfall-runoff and runoff-sediment relationships in Yom river basin of Thailand by comparing land use land coverage change (LULCC), rainfall-runoff pattern, and sediment load in the main river course from 1980s to 1990s and to 2014. The results indicate that from 1990 to 2014, many forests in Yom river basin have been significantly transformed into farmland and irrigation area, especially in high-slope locations relatively further away from the main river course. This change of land use pattern has consecutively altered the rainfall-runoff and runoff-sediment relationships, and lead to more pronounced slope of trend curve (STC) of annual rainfall-runoff and runoff-sediment mass curves in 1990s compared to 2000s, implying that more soil and water loss yield in 2000s. One can logically suggest that the runoff-sediment load obtained during 1990s is higher than 2000s with similar rainfall/runoff, which can further be explained by the historic landuse dynamics. Double mass curve with STC analyses is proved to be an efficient method to preliminary assess the overall change of physical and hydrological conditions of the watershed with logical domino effects from upstream to midstream and to downstream. With the new water allocation scheme in Yom river for flood risk reduction in the lower Chaophraya river basin, agricultural practices have spatio-temporally changed and parts of Yom river basin have been used for flood retention areas, significant alteration in rainfall-runoff and runoff-sediment patterns has started to be monitored (i.e., in Bangrakam and Kongkrailart Districts) and will be consecutively studied with more observation points at the local scale. Continuous reduction of forest fraction results in soil loss, landslide, river bank erosion, and flood occurrence results in a more degrading river water quality and potential decrease in river capacity for flood protection, all involved stakeholder such as local authorities, communities, farmers, and policy makers should pay attention to apply appropriate land use and watershed management and flood risk reduction practices.

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