Dynamic Model Of Suspended Sediment Concentration, River Discharge And Rainfall Intensity At Padang Watershed North Sumatra, Indonesia

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Abstract : Sediment transport has relationship with hydrologic input primarily river discharge and rainfall intensity. Fluctuation of river discharge and rainfall intensity have great effect on suspended sediment concentration. Bayesian Dynamic Linear Model (DLMs) is used to study relation of input hydrology and basin response variables. Response variables were taken from suspended sediment concentration and river discharge from a year July 2012 to June 2013 at two outlets at Padang sub-watershed (upstream) and Padang Hilir sub-watershed (downstream) of Padang watershed, North Sumatra. Datas were analyzed by regression analysis of Suspended Sediment Concentration (SSC) as a dependent variables, while river discharge and rainfall intensity as independent variables. The results showed that river discharge value are the highest on July 2012 and October 2012 at upstream and downstream of Padang watershed, respectively. The SSC value are the highest on July 2012 and April 2013 at upstream and downstream of Padang watershed, respectively. There is a weak correlation (r^2= 0.002) between SSC and rainfall intensity at source points of outlet at upstream of Padang watershed. There is decreasing of forest, paddy and plantation areas but increasing of bush and farming areas from 2012 to 2015 at upstream of Padang watershed. Meanwhile at downstream of Padang watershed were increasing of plantation areas since 2012 to 2015

Keyword : dynamic model, suspended sediment concentration, river discharge, rainfall intensity, Padang watershed

1. Introduction

Highly dynamic of river systems of are controlled by a complex of ecologic, climatic, and geomorphic processes. The movement of sediment at river system is difficult to predicted and controlled (Steegen, *et al*, 2000), at least in part of sediment results from soil and channel erosion in the past. Sedimentation is primary problem of water channels because affected by human activities, such as forest conversion into farming, road construction, mining, and growth sub urban dan urban communities. Meanwhile, Suspended Sedimentation Concentration (SSC) is influenced by channel boundary conditions, runoff and sediment load. The sedimentation rate and channel adjustment exhibit marked downstream variations. The rate of vertical natural levee deposition shows a tendency to decrease downstream.

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At upstream of Padang watershed occur land use change of forest into plantation, farming, paddy, bush and urban land. Forest land declines about 2.35 percent from 2012 to 2015 (Ministry of Forestry, 2015).Frequency of rainfall intensity is lower but the erotion still continue, then the newly formed edge and floodplain cannot receive sediment load from riverbank. After some sediment load has been deposited on the floodplain, the sediment concentration of riverbank water flow decreases (Meade, 1982). Backgrounded by above condition, we interested to detect changes in sedimentation due to changing land use. The availability of time-series data during a period after rain more needed to testing new methods that can address changing sedimentation response. Relationship between SSC and river discharge (Q) hysteresis were widely examined at the event scale to interpret geomorphic processes and outline the spatial distribution of sediment sources (Crawford, 1991; Duvert, et al, 2010; Iroume, 1991; Krishnaswamy, et al, 2000; Krueger, 2009). According to Lubis, et al (2013) there is very strong correlation between suspended sediment concentration and river discharge at six months from July to December 2012 at some outlets of upstream Padang watershed after rain (r2 = 0.88). Conversely, there is very weak correlation between suspended sediment concentration and river discharge at six months from July to December 2012 at some outlets of upstream Padang watershed at no rain (r2 = 0.06). Based on these studies, the SSC–Q relationships can be mainly classified into three classes. First, peaks of SSC and discharge arrive simultaneously. Second, the SSC peak arrives earlier than the discharge peak and third, the SSC peak arrives later than the discharge peak. The mechanism behind the second class may be the remobilization of in-channel sediment deposits or adjacent extra-channel sources where sediment is transported by short distance of runoff (Jansson, 2002; Walling, 1997). The third class may be related the arrival of remote sediment from external channel sources during long duration rainfall events or correspond to the absence of sediment channel (Brasington and Richards, 2000; Krishnaswamy, et al, 2000; Owin and Smart, 2004). However, little study has been done on the suspended.

2. Materials and Methods

2.1. Location

Padang watershed is located at three administration areas, that are Simalungun, Serdang Bedagai Districts and Tebing Tinggi City, North Sumatera.This wátershed is divided into seven sub-watershed where the upstream is located at Padang sub-watershed and the down streams located at Padang Hilir sub-watershed. The upstream zone located at Padang sub-watershed and has 30276.276 ha in area. The dowsnstream zone located at Padang Hilir sub-watershed and has 17677.277 ha in area. This area is managed for plantation, farming, paddy ,forest and urban.

2.2. Water and Parameters Sampling

Water samples are taken at source points of the two outlets that are at upstream and downstream of Padang watershed by using integrating depth method (Asdak, 2002). Water samples are collected at three (3) source points that are at left, center and right side of the river wet surface. Every water sampling is done the width and depth of river is determined at left, center and right side, too. This measure is used to calculate the cross section area of river (m^2). The velocity (V) is determined by floating method. The cross-section area (A) is obtained by multiply width of river wet surface with depth of river (Chow, 1985). The velocity ($m.s^{-1}$) of the river flow is determined by calculate duration of the plastic bottle which is threw flow as far as 20 metres (Asdak, 2002). This measures are done at three times a week from July 2012 to June 2013 at no rain and after rain. Daily precipitation datas are taken from Rambutan and Brohol Stations.

2.3. Analysis Method

The specific object of this study was to obtain the model of the suspended sediment concentration response to river discharge and rain intensity. Datas were obtained be analyzed by using Bayesian Dynamic Linear Regression Models. This model will detect relationship and short term trends in suspended sedimentation concentration response to river discharge and rain intensity. The dynamic sediment suspended concentration from a basin can be modeled as a simple function river discharge. The transport of sediment has great variety based on supply function of sediment showed by this function :

$$S_t = f_1(E_t, T_t, SU_t) \qquad (1)$$

$$\delta S_t/\delta_t = f_2(\delta E_t/\delta_t, \delta T_t/\delta_t, \delta SU_t/\delta_t) \qquad (2)$$

where S_t, T_t, E_t *and* SU_t are sediment output, transport capability, rainfall erosivity and sediment supply from the basin, respectively and $\delta S_t/\delta_t$, $\delta E_t/\delta_t$, $\delta T_t/\delta_t$ and $\delta SU_t/\delta_t$ are rates of change, respectively. The relationship between river discharge and suspended sediment concentration (SSC) is generally expressed by a rating curve, which is described by a power function (Huang, 2011; Lenzi and Marchi, 2000; Meade, 1982; Mimikou, 1982) :

$$SSC = aQ^b \qquad (3)$$

in which SSC or C_t is the suspended sediment concentration (g/m^3), Q is the river discharge ($m^3.s^{-1}$) and area, geomorphology, vegetation, and hydroclimatic factors (Arnett, 1979; Bogardi, 1961; Huang, 2011; Meade, 1982; Muller and Foster, 1968; Piest and Miller, 1975; Van Sickel and Beschta, 1983). In general, the coefficient a will be higher (all else being equal) for watershed with higher rates of sedimentation. Thus the coefficient a functions as a base line supply parameter. Constant b may be considered a measure of rate at which hydrologic energy is converted to geomorphic work (Meade, 1982; Rannie, 1978). Changes in b over time at a gauging station could be an indication of increasing sensitivity of the upstream watershed to hydrologic forcing. Many researchers have related parameter b to the availability of sediment in relation to available hydrologic energy. However, various studies (Jansson, 2002; Steegen et al, 2000; Van Sickel and Beschta, 1983) showed that the relations between suspended sediment concentration (SSC) and Q are highly variable either within or between events. In this paper we follow the basic procedure and consider Bayesian Dynamic Linier Model a, b are empirically determined regression. In practice, log transformed sediment concentration and corresponding flow at a gauging station have been used to fit static linear regression models :

$$\log_{10}C_t = a + b\log_{10}(F_t) + \varepsilon \qquad (4)$$

The parameters a and b (or A and B) may reveal watershed and channel characteristics, including with observation equations using a daily time-step:

$$\log_{10}C_t = a + b\log_{10}(R_t) + \varepsilon \qquad (5)$$

where: C_t is daily volume-weighted sediment concentration, F_t is daily river discharge and R_t is rainfall intensity. Application of the Bayesian Dinamyc Linier Model demonstrates that a graph of the back-filtered estimates of the regression coefficient or slope of rainfall erosivity provides a much stronger and convincing evidence for a real change in basin erodibility (Krueger, 2009). Since there is no term for supply, changes in sediment availability related to land-surface conditions will be reflected in the temporal dynamics of coefficient b. Changes in the parameters Bt over time due to land surface processes such as forest conversion, reforestation and urbanization will be the main focus of the analyses. The river discharge at some source points at outlet of upstream and downstream are calculated by using Bernoulli equation (Asdak, 2002) :

$$Q = A \times V \qquad (7)$$

where : Q is river discharge ($m^3.s^{-1}$), A is cross- section area (m^2) and V is velocity of stream flow ($m.s^{-1}$).

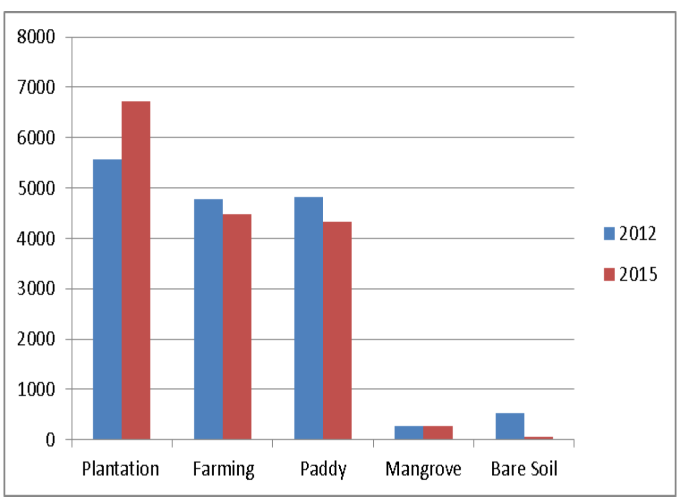
3. Results and Discussion

3.1. Land Use

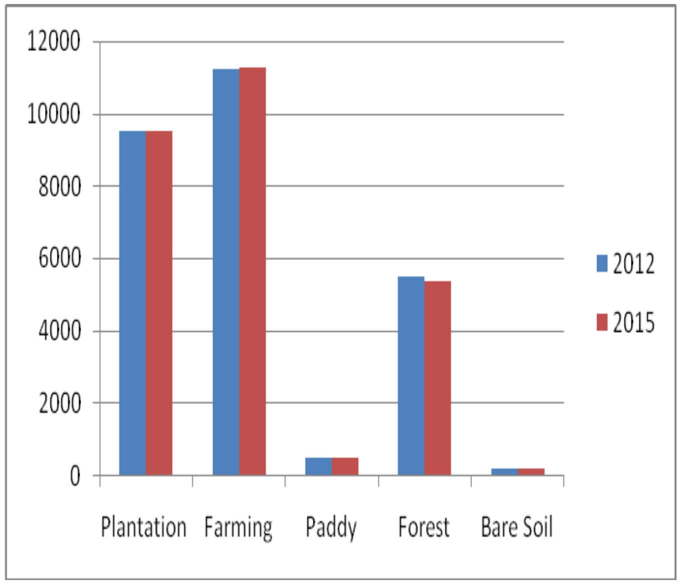
There is land conversion from 2012 to 2015 at Padang (upstream) and Padang Hilir (downstream) of sub-watershed into other land use like for plantation, farming and paddy (Fig. 1). Land use change at Padang watershed is mainly into plantation land. There is decreasing of forest, paddy and plantation land area bout 2.35, 8.03 and 0.09 percent and increasing of brush and farming land area from 2012 to 2015 about 5.15 and 0.16 percent at Padang sub-watershed (upstream of Padang watershed), respectively. There is decreasing of mangrove, farming and paddy land area about 1.75, 6.5 and 10.08 percent and increasing of plantation land area from 2012 to 2015 about 21.00 percent at Padang Hilir sub-watershed (downstream of Padang watershed), respectively.

3.2. Time-series data concentration of suspended sediment, river discharge and rain intensity

Comparisons of the time-trend of suspended sediment concentration, the river flow and rain intensity at the upstream and downstream of Padang watershed are presented at Figs (2-3). There is stable suspended sediment concentration (SSC) and river discharge approached the first class of relationship where the peaks of SSC and discharge arrive simultaneously at outlet of Padang watershed. Conversely, the relationship value of river flows at upstream outlet of Padang watershed at January to June, the maximum value occurred at July and drastically decrease at August to December. Suspended sediment concentration at upstream outletis the lowest at November as rainfall intensity decline at that month. It was indicated by low velocity of river discharge at October and November (Fig. 2). Kinetic energy of rainfall will transport sediment into level part of river and accumulated on it. In fact, we can see that monthly average of SSC at downstream outlet are over 30 mgL^{-1}.



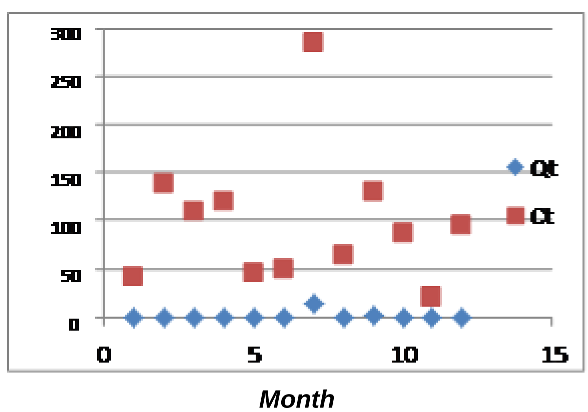
(a)



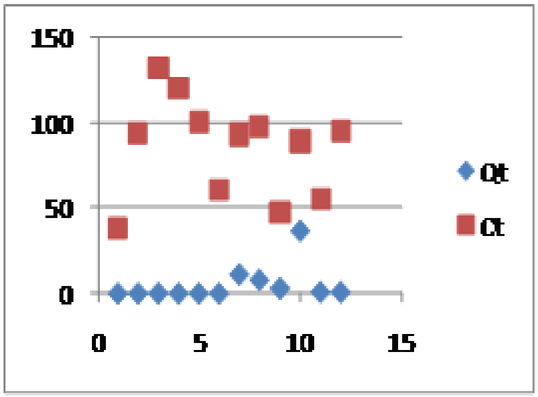
(b)

Fig. 1. *Land use at Padang Hilir (a) and Padang (b) sub-watershed based on satellite interpretation in hectar*
(Source: Ministry of Forestry, 2015)

There is stable value of river discharge at downstream outlet at January to June, but increase at July and reaches the maximum value at October. The SSC at upstream outlet is the lowest at November as rainfall intensity decline at that month. It was indicated by low velocity of river discharge at October and November (Fig. 2). Kinetic energy of rainfall will transport sediment into level part of river and accumulated on it. In fact, we can see that monthly average of SSC on at downstream outlet are over 30 mgL^{-1}. At the downstream outlet monthly average of rain intensity lower than at upstream outlet under 15 mm. It means that there are no turbulence at river which can transport the sediment load so SSC will increase along surface of river. It could be seen from high turbidity level primarily after rain.



(a)

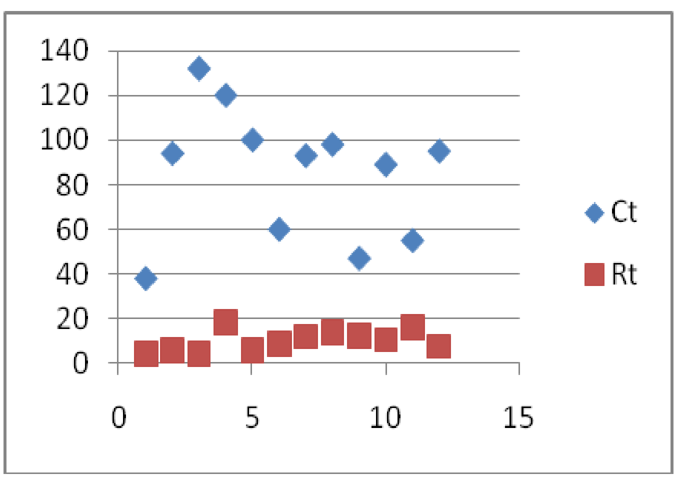


Month
(b)

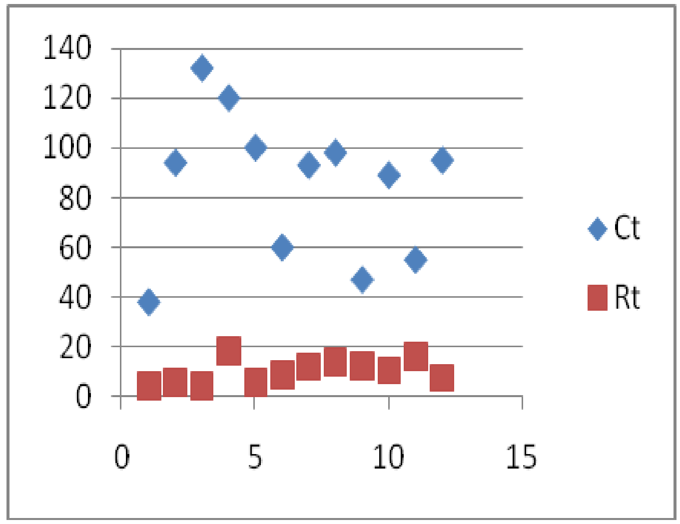
Fig 2. *Time-series monthly of river discharge (Q_t) and suspended sediment concentration (Ct) at upstream (a) and downstream (b) outlet of Padang watershed (July2012 to June 2013)*

3.3. Dynamic Regression Coefficients

A regression coefficient that changes over time is indicated from the changes in the process that links the independent variable to the response variable. Analysis of the Bayesian DinamycLinier Model (DLM) yields time-series of estimates of b_t, the regression slope at time t Figs. 5-6 show how the slope changes over time for regressions Eq. (5-6) at outlet of Sub DAS Padang Hilir (downstream of Padang Watershed). Application of Bayesian DLM at annual data shows that increasing of river discharge provide decreasing of suspended sediment concentration (SSC) at upstream outlet of Padang watershed. Application of the Bayesian DLM shows that a graph of the back-filtered estimates of the regression coefficient or slope of rainfall erosivity provides much stronger and convincing evidence for a real change in sub-watershed erodibility.



Month
(a)



Month
(b)

Fig 3.*Time-series monthly suspended sediment concentration (C_t) and rainfall intensity (R_t) at upstream (a) and downstream (b) outlet of Padang Watershed (July 2012 to June 2013)*

At upstream outlet of Padang watershed occurred increasing of SSC as rainfal intensity increase overtime. Conversely, at downstream outlet of Padang watershed occurred decreasing of SSC as rain intensity increase overtime.

(a) $\text{Log}C_t = 1.72 - 0.004\log_{10} (F)_t + \varepsilon_t$:
$r^2 = 0.002$

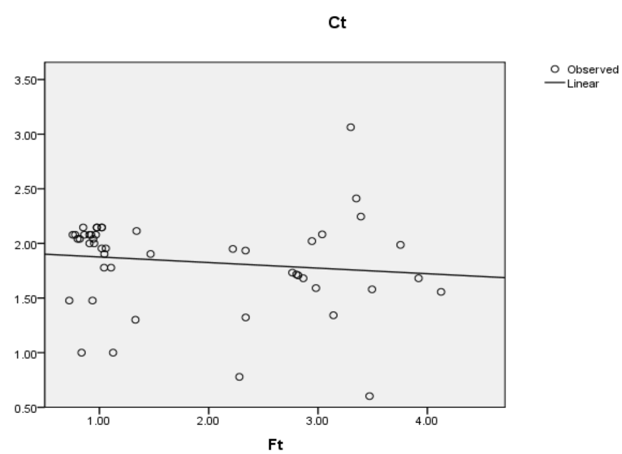
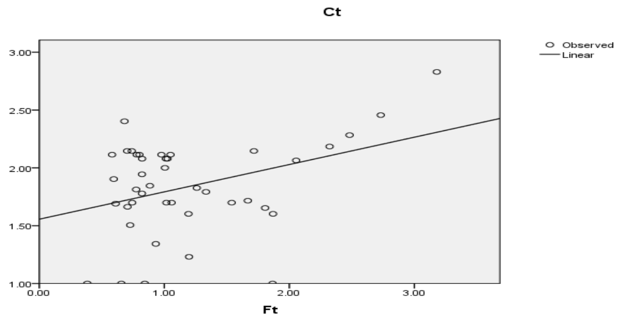
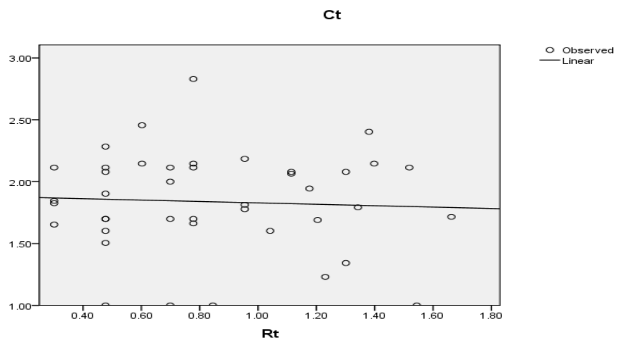
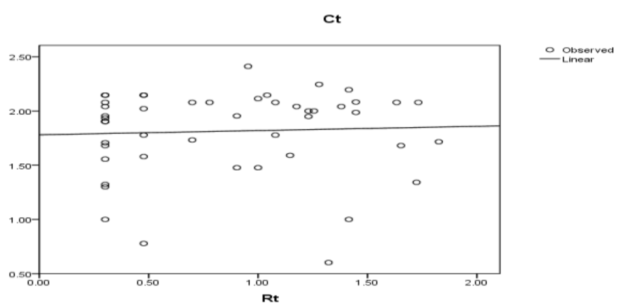


Fig 4 *. Time–series of suspended sediment concentration (C_t) and river discharge (F_t) monthly at outlet of downstream (a) and upstream (b)Padang watershed*





(a)Log $C_t = a_t - b_t \log_{10} (R)_t + \varepsilon_t$: $r^2 = 0.002$



(b) Log $C_t = a_t + B_t \log_{10} (R)_t + \varepsilon_t$: $r^2 = 0.003$

Fig 5.*Time–series of suspended sediment concentration (C_t) and rainfall intensity R_t) monthly at outlet of upstream(a) and downstream (b) Padang watershed*

4. Conclusion

Land use change of the forest into another land use results decreasing of bare soil about 86.75 percent at Padang Hilir sub-watershed (downstream of Padang watershed). The highest land use change at Padang Hilir and Padang sub-watershed is into farming and plantation area that are 5.15 and 21.00 percent, respectively. There is stable suspended sediment concentration (SSC) and river discharge approached the first class of relationship where the peaks of SSC and discharge arrive simultaneously at some souce points at two outlet of Padang watershed. There is very weak correlation between SSC and river discharge on July 2012 to June 2013. Such was the case there is very weak correlation between suspended sediment concentration and rain intensity on July 2012 to June 2013. In general the dynamic regression approach would not suitable for assessing changes in relationships between SSC on to river discharge and rain intensity overtime at some outlets of Padang watershed. These are could be related by many factors may influence SSC, like land-use change or shifts in hydro-climatology. However, impact of infrequent river discharge may influence on sedimentations are more easily detectable using this method. The changes of source points in water sampling may influence content of SSC, too. Beside that such points and events sedimentation process under water could not be predicted certainly. These approaches need to be applied to other hydrologic and geophysical longer time-series data where there is an identified response variable and one or more explanatory variables. This will lead to an enhanced understanding of the dynamism of hydrologic systems and their sensitivity to climate change as well as anthropogenic influence.

5. Acknowledgments

The author wish to thank for Erwin Masrul Harahap, Abdul Rauf and Zainal Arifin Hasibuan. This work was supported in part from the University of North Sumetera Grant.

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