Spatial pattern of sediment transport for analysis of precipitation direction and magnitude in the Upper Lematang watershed

by Dinar Da Putranto

Spatial pattern of sediment transport to analyse direction and magnitude of deposition in the Upper Lematang watershed

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Abstract. The high level of erosivity that occursin Musi sub watershed has increased a tremendous impact on sedimentation in downstream areas and has resulted in many water infrastructure damage , such as silting of irrigation channels, aggradation of rivers which has disrupted the flowrate, has increased the risk of flooding, high sedimentation in the port basin , low quality of water which caused rising costs of water treatment. This study utilizes techniques terrain models Digital (Digital Elevation Model/DEM) to analyse the spatial distribution of the potential for erosion and sources of sedimentation, as well as the direction of the flow of sediment into channels and its relationship with outlet in branching river as the supplies to be sediment to the river flow. The method used in this study is a spatial model analysis using GIS in analysis and presenting the level of erosion and deposition by utilizing modelling slope and kinetic energy of rainfall to estimate the index erosivity and distribution pattern of sediment into the river channel. This research was conducted at the sub-watershed Upper Lematang and central parts with area 215,000 Ha, which are classified into 11 sub-chatments with the highest altitude is 3.159 m above sea level (Dempo Valley) and the lowest is 126 m above sea level (TalangTinggi Valley).. Overall, high intensity erosion tends to occur in the relationship between the different vegetation coverage, the barren land and open land used for farms and land used for mining. Approximately 45-65.5% slope is in bad condition with no vegetation or open land, so it can be seen the amount of erosion in the area is 2.139 ton/ha/year, while at them order at sloping area is 1.8239 ton / ha / year.

***Key words** : erosivity index, kinetic energy, DEM, GIS, sedimentation*

1. Introduction ,

Soil erosion is a natural process that occurs naturally, but is generally accelerated by various human activities such as inappropriate farming activities (Risser, 1981). Negative effects of soil erosion is expressed in two as a result, the on-site erosion and off side erosion . Effects on the location of soil erosion is the loss of fertile layer of the soil surface for agricultural activities, and land slide. While off-site effects of erosion is the loss of soil particles that cause sedimentation in the direction toward the estuary of the river flow and can reduce flow capacity of the river, increase the risk of flooding, and accelerate its reservoir sedimentation (Morgan, 2005).

River flow does not only work as sediment transport but also ifluences river bank erosion so that it in reases the amount of transported sediment.

Material that is eroded or sedimentation material from hill slope, is partly deposited back in the slope system and some of it is flowed into the river, according to the comparison of the existing slope (Phillips, 1991). Thus the number of lost material of slope system that will produce spatial patterns of erosion and deposition of sediment.

2. Methodology

2.1. The process of erosion

Erosion is a process or event of loss of topsoil, both caused by movement of water and wind (Suripin, 2004). Erosion is three sequential process, namely the release (*detachment*), the appointment of cutaneous (*transportation*), and sedimentation (*deposition*) material ground by causing erosion (Asdak, 1995).

In humid tropical regions such as Indonesia, water is the main cause of erosion, whereas for hot, dry areas wind is the main cause. Erosion is the removal of soil or rock particles by natural agents such as water and wind, and is accelerated by human activity. The main factors of soil erosion that remove soil particles is the rain. There are two main processes, namely the release caused by rain falling on the ground and runoff. This erosion is also exacerbated by pressures on the land, specifically agricultural land management (Boardman, 2001 in Suripin, 2004).

2.2. Factors affecting erosion

Erosion layer from the soil depends on the nature of the rain, soil resistance to rain dropand the movement of water above the ground surface as surface runoff. The following understanding of erosivity, erodibility and speed of grinding (Soemarto, 1987)

2.2.1. Erosion. Erosivity is a characteristic of annual rainfall. low intensity rarely cause erosion, but heavy rain with short and long periods may cause substantial runoff and soil loss. The nature of raindrops that affect erosivity is seen as the kinetic energy of raindrops that hit the soil surface. Rainfall that falls directly or indirectly can erode the soil surface slowly with increasing time and accumulation of rainfall intensity will bring erosion (Kironoto, 2000).

Kinetic energy of rain (E , in the Joule/m^2) is influenced by average annual rainfall (R) and rainfall Intensity (I) , can be derived from the equation , Smith and Weischmeier in Soemarto (1987)

$$E = 210.3 + 89 \log_{10} I \qquad (1)$$

To get the energy kinetic rain with rainfall intensity for 30 minutes (I_{30}), then the above equation becomes ,

$$EI_{30} = E \times (I_{30} \times 10^{-2}) \qquad (2)$$

EI_{30} Rain erosivity index ; E, Total rain-typed energy (Joule/m^2) ; I_{30} Max rainfall intensity for 30 minutes .

2.2.2. Erodibility. Flow strength model (sediment transport) is done by estimating the conservation of mass to simulate soil erosion and sedimentation. The average change in soil loss E (tons / ha / year) is predicted through the approach of the RUSLE equation (Renard et al, 1996 in Narcisa G Pricope, 2009). RUSLE Model (Revised Universal Soil Loss Equation) is the development of a model USLE which is an empirical model to estimate erosion surface and related to the surface runoff:

$$E = R.K.LS.C.P \qquad (3)$$

Where E is rate of soil erosion (tons / ha / year) ; R is Rain Erosion Factor ; K is soil erodibility factor ; LS is Slope length and slope (steepness of slope) ; C is is land management factor (coefficient of infiltration of vegetation cover) ; P is Index of land management or soil conservation measures .

The factors R, K, C, and P have been determined empirically (Renard and Freimund 1993, Wischmeier and Smith, 1978, Zaluski et al., 2003). The LS factor , is calculated to predict the strength / erosivity of the Run-off and is expressed as the ratio of soil loss that is affected by the slope and length of the slope . For lost ground on standard conditions, at an inclination of about 5° (9%) with length slopes about 22.13 meters (Wischmeter and Smith, 1958) , is determined by the equation

$$LS = (\lambda/22,13)t\ (65,4\ Sin^2\beta + 4,56\ Sin\ \beta + 0,0654) \qquad (4)$$

where λ is the slope length in meters (horizontal projection of slope length in meters), β is the tilt angle (degrees), and t is the length exponent which depends on the steepness slope, with a value of 0.5 on slopes exceeding 5%, 0, 4 for the average slope between 3-5% of the slope, and 0.3 for the slope of less than 3% of the slope. Utilization of this formula, as the formula used standards, has failed to take into account the complexity of the topography, in areas with no slope, it has never contributed to the delivery of sediment. For example (Kinnel, 2004), argues that the use of sediment delivery ratio defined in the USLE , does not take into deposition of sediment, while the sediment deposition often occurs on the hillside .

The Unit Stream Power Erosion and Deposition Model or USPED (Mitasova *et al*. 1996, Mitas and Mitasova 1999) is used to predict the spatial distribution of erosion and deposition levels for condition stable flow associated with conditions caused by rainfall. Map of erosion and deposition are generated in this study, will be tested in the central region of sub-basins Lematang middle , with some of the division of sub-basins. By using USPEDmodel ,the map ca be as an indicator to see which areas of land form most likely supplies fine sediment to the channel network, and to get a quantitative index of sediment which supplies to the channel network .

USPED models assume that the transport of sediment on the slopes have a limited capacity, which means that the sediment transport rate is determined by the power of flowing water erosion, and are not limited by the supply of soil particles which are transported. Thus it is assumed that the sediment transport rate is obtained from the equation :

$$qs = K_t\, q^m \sin^n b \qquad (5)$$

where b is the slope of the local surface (degrees), q is the flow rate of water per u nit (m2 / sec), K is the coefficient transportability soil (depending on the properties of soil and vegetation cover), and m and n are constants dependent on the type of flow and soil characteristics. Equation 5 gives sediment flux (volume per unit width, m^2 / s) in the direction of maximum slope gradient.

The value of exponent (exponent slope / steepness) varied and is analysed in accordance with the shape of the slope, the type of land cover (land cover) , and also the occurrence of erosion. Thus, various exponent values have been determined for different climates, the standard fire for the United States (Morgan, 2005, p.58) is around 0.3-1.0 for high rainfall and around 0.7 and 1.7-2.0 each for *detachment* and transportation on soil particles with surface flow (surface erosion). Kirkby (1971) quoted by Morgan (2005) shows that the length of the slope of the exponent *m* ranges from 0.3 to 0.7 for surface flow and rises to between 1.0 and 2.0 in the case of rapid flow. The value used in the model USPED to *n* (1.3) has been in use right to be the exponent of the most appropriate for use in the equation RUSLE by lowering the theory of power flow (Moore and Burch, 1986; Moore and Wilson, 1992). For surface flow, the constants *m* and *n are* set for : m = 1.6 and n = 1.3.

Steady-state water flow can be expressed as a function of *upslope* contribution per unit counter width A [m2 / m]

$$q = A.i \qquad (6)$$

where i [m / s] is the average rainfall intensity. Thus Equation 3 can serve back shortly so :

$$q_s = Kt\,(A.i)^m \sin^n b \qquad (7)$$

These formulations are limited because there is no experimental work has not been done to give the value of the parameter K_t (Mitas and Mitasova, 1999). If assumed that $K_t \sim$ KCP and $i_m \sim$ R, then the magnitude of the relative sediment flux can be estimated from the USLE formula as :

$$q_s = R.K.C.P.A^m.\ \sin^n b \qquad (8)$$

where the constants m and n has a value of 1.6 and 1.3 respectively is expired u for real erosion and 1 to erosion surface (Mitas and Mitasova 1999, Clarke et al., 2002). This equation is power flow erosion which combine values empirically derived from USLE parameters. As a comparison for RUSLE (equation 3), it can be seen that LS ~ $A^m \sin^n b$. Since USPED equation is a hybrid between RUSLE and power flow based on transport models, the results of the USPED model present the relative direction of the average soil erosion and deposition rate of the soil losses which are rather specific and expressed in ton/hectare/year. This issue is an issue that needs to be considered by stakeholders to make comparisons of calculations in estimating the magnitude of erosion in the watershed .

Average erosion or deposition (ED) is given by the two dimensions (horizontal plane) differences in sediment fluctuations that express mass conservation

$$ED = \text{div}\,(q_s) = d\,(q_s \cos a) / dx + d\,(q_s \sin a) / dy \qquad (9)$$

where a is an aspect of the terrain surface (the direction of the gradient of the maximum slope at horizontal angles in degrees). Models of sediment transport (equation 8) combine with right to the conservation of mass (equation 9) describe the spatial pattern - average of overland flow (and thus the area of the upstream contribution, equation 6). Meanwhile a gradient slope and control aspects of the topography give a donation to the distribution soil erosion and deposition.

Equation for sediments flux (equation 8) and sediment flux difference (equation 9) is used to calculate the effect of topography on to slope and direction of transport and the resulting patterns of erosion and deposition. Map erosion and deposition derived in this study, namely sub-basins upstream Lematang and individual sub-basins central Lematang by applying the model USPED (equation 8 and equation 9) in order to use this map as a visual indicator spatially to predict which areas are most likely to be a supplier of sediment to the channel network, and to obtain a quantitative index of the supply of sediment to the channel network

3. Implementation of the model

Elevation, soil type, land cover, and hydrograph data for the upstream Lematang sub-basin research area were obtained from a number of sources. The spatial data is used to derive the parameters needed in the soil loss equation (equation 3), where the spatial modelling approach is carried out.

3.1. Index topography (factor direction and slope of the land)

The topographic index is calculated using GIS aid, through DTM or Digital Elevation Model (DEM) modelling with pixel sizes of 10 m and 25 m, from SRTM data obtained from the Geospatial Information Agency (BIG). The analysis was conducted based on data contour elevation to obtain slope, length of the slope, and div. X and Y directions from the slope.

3.2. Rain Intensity (I_{30})

The amount of rainfall (D) is a function of increasing kinetic energy (KE), soil susceptibility index (Kd) and the percentage of INT rainfall interception . Annual kinetic energy can be calculated from the graph output rain observation station using equations or alternative in estimate of rainfall data using empirical equations . To calculate the amount of kinetic energy at work in the area, then the intensity of rainfall for 30 minutes (I_{30}) is used. Based on these data from the calculation of rainfall intensity. Rainfall data uses daily rainfall data for ten years (2007 -2017) for three observation stations at the research location, namely PTPN VII (PagarAlam), PagarAlam Police Station, and Jarai Station (North PagarAlam) . From Data at three locations observation stations that, further analysed to obtain the spatial distribution with polygon Thiesen for rain intensity thirty minutes (I_{30}) of each month with the 5 years repetition.

Table 1. Intensity 30 minutes (I_{30}) monthly rainfall , three observation stations in the research area of the upper Lematang sub-watershed

Station	Rain Intensity (I30)											
Month	Jan	Feb.	Marc	Apr	May	June	July	Aug	Sept.	Oct	Nov	Dec
PTPN	7.95	9.21	8.90	10.95	8.436	7.21	9.77	8.21	8.64	8.355	12.376	8.996
Police station	8.043	8.89	8.459	7.905	9.460	7.512	7.19	6.31	6.154	9.776	10.63	9.016
Jarai	7.95	9.21	8.902	10.95	8.436	7.212	9.77	8.21	8.642	8.355	12.376	8.996

Source: Analysis Results, 2019

3.3. Erodibility Factors (K)

Soil erodibility (endurance soil) can be determined by the rules of the formula calculation of the K value that can be calculated by equation (Weischmeier, et al, 1971) , with the parameters of the particle size of the ground (M) , ingredients organic (a) , the dignity of ground structure (b) and the soil permeability value (c) . The K value can then be determined based on the type of soil in the study area as in table 2 below.

Table 2 . K value is based on the type of soil in the study area .

Type of Soil	*K Index*	Type of Soil	*K Index*	Type of Soil	*K Index*
Alluvial	.156	Red Podsolic	0.166	Red Brown and Yellow Red la tosol	0.046
Andosol	.278	Yellow Podsolic	0.107	Yellow Podsolic and dark hidromorf	.249
Yellow brown Andosol	.298	Yellow brown Latosol	0.091	Red Brown Latosol and Brown Latosol	0.067
Andosol and Regosol	.271	Regosol and brown latosol	0.186	Red Brown Latosol and Red Latosol	0.061
Latosol	.176	Brown Latosol	0.175	Red Yellow Podsolic	0.166
Regosol	0.075	Redbrown Latosol	0.062	Dark blue Regosol and Litosol	0.29 0

(source : Centre for Irrigation Bandung, 2015)

3.4. Land cover and management factors (C) .

Based on interpretation of satellite imagery resolution of 5 m, the data is classified based on land use and value for the C factor. Because the lowest level of land use in the study area was used for mining and open land, the highest value used for land coverage was 0.65. While for non-irrigated agricultural land is different from the use of irrigated agricultural land, C values are used, 0.43 for non-irrigation and 0.02 for irrigated agriculture. Meadows and areas covered by shrub vegetation, depending on the level of coverage, for undisturbed shrubs the value of C = 0.01, while partially grassy shrubs used a value of C, 0.10 . While plantation region, given the value of 0.1, while the forest, which provides the highest level of protection, in use low value of C (lower than 0.03).

3.5 Support for land management factors (P)

The P factor is used constant prices (equal to 1) in the analysis because there are insufficient reliable data sources needed to conduct analysis of the various conservation practices that are applied in the watershed of the study area. Thus, the resulting analysis does not account for differences in erosion and soil lose because of differences in the way of planting and practices of land use.

4. Results and Discussion

4.1. Transport sediment and sediment analysis.

Sediment transport analysis uses the USPED (Unit Stream Power Erosion and Deposition) method. The patterns model for sediment transport and erosion and sedimentation rates in the upper Lematang watershed were analysed for three categories of causative factors, namely topography, topography based on soil erodibility, and topography affected by soil erodibility and land cover. Also, including analysis of both surface runoff and erosion mechanisms, real flow is calculated using all the triggering factors that affect erosion. In the USPED model, the slope factor is influenced by the topographic index, which will affect the K value (soil erodibility), and also influenced by the C value (land use) and P (land management factor) to obtain the value of sediment transport. Results from the analysis of sediment transport and deposition, in sub-watersheds are classified for each sub chatment. Exfoliation and sediment rates are classified according to the catchment area of each watershed, to obtain ED values in accordance with sub-watershed boundaries

Table 3 . Value of sediment transport each sub-basin

Name Sub Ba sin	Area (ha)	Sediment Transport (ton/ha/Year)	Average ED (tonnes / ha / Year)
Sub Basin 1	3,808.3	1.794	-2.303
Sub Basin 2	2,241.4	1.176	1.26 5
Sub Basin 3	4,228.6	2.889	-1.651
Sub Basin 4	3,948.9	0.166	-0.456
Sub Basin 5	4,773.8	5.953	1.417
Sub Basin 6	4,423.1	2.832	-0.528
Sub Basin 7	2,975.7	0.243	-1.193
Sub Basin 8	5,914.0	0.161	0.001
Sub Basin 9	2,014.0	0.175	-0.037
Sub Basin10	4,133.0	0.483	-0.380
Sub Basin 11	5,266.2	0.281	-0,179

Based on the above analysis it was found that sub-basin 1 has a fairly high erosion rate of 2.3035 tons/ ha/year. While sub-basin 5 is a maximum sediment deposition area of 1.417 tons/ha/year. If the distribution of sedimentation is analysed based on various factors such as land use and land slope, the results can be seen in the following figure.

4.2. The average transport of sediment and erosion spatial distribution and deposition based at slope aspect and land use

Based on the results of overlapping various slope levels with the infiltration coefficient (C) of land use, erosion yield obtained for each land use, and the average value and sedimentation build up as shown in Table 4. ED classification results (flaking from the ground up) based on land use, it appears that the largest exploitation are found in the area of agriculture with irrigation 2.139 ton/ha and sediment in the area of water at 5.226 tons/ha. A low C value indicates that it is naturally more protected from erosion by land flow compared to plantation and agricultural land which is less resistant to erosion and has the highest C value. The effects of factors transport sediment is going to reduce the sediment flux in areas that are well protected by vegetation cover and will increase in areas that are less protected by a deeper root system. The inclusion of a factor C, significantly alters the distribution area to the rate of sediment transport is high, making the effect of the topography becomes unclear and will affect an area that has a vegetation cover with protective vegetation cover is low, such as in the area with patterns of drainage main -covered forests and plantation, with the area of reservoir.

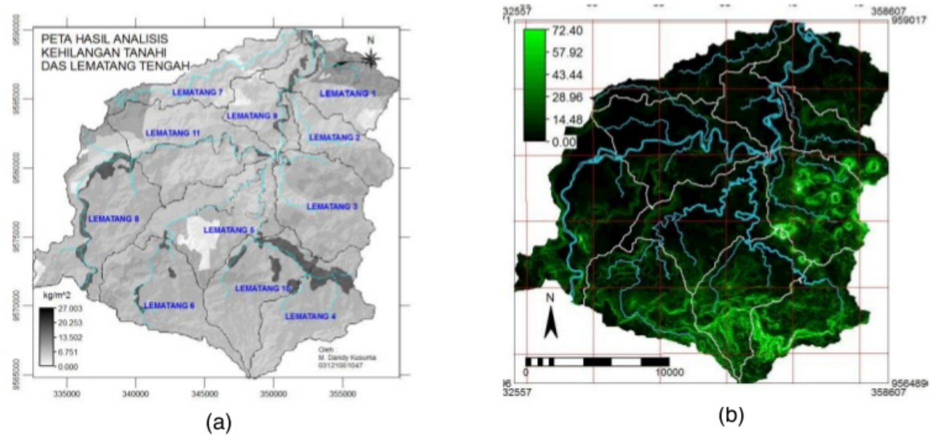

Figure 2. (a)Average sediment transport of upstream-midle stream Lematang watershed and (b) deposition results from various variations of various combinations of factors in the USPED model

By adding a factor in the calculation of land cover, erosion patterns and deposition will shift and you will see areas with high erosion and the risk of deposition occurs at the contact between agriculture/pasture and forest land, and seen on the slopes with a slope of between 15-25 % less protected by vegetation cover. This occurs as a result of changes in sediment transport rates associated with the transition from one land cover to another. For example, an increase in the rate of transport towards the valley (as determined by the local topography) will cause erosion .

Table4. Average Sediment transport and spatial distribution of erosion and disposition as a result of slope and land use classification

Land Use	Area (Ha)	Average Value of ED
Village	9,191.875	0.8045
Irigation	1,640.8125	-2.1390
Dryland	5,448.3750	2.1207
Garden	4,004.8125	-0.3282
Plantation	2,0581.1250	0.1467
Open Field	3,421.8125	-0.1521
Forest	10,753.7500	0.4978
Water	800.4375	5.2258
Open Land Use	36.5625	-0.0526

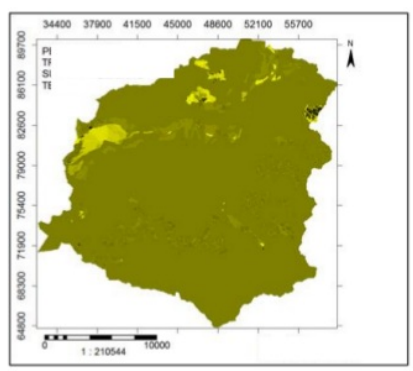

Figure 3. Sediment transport rates and erosion and sediment distribution patterns as a result of land use changes

4.3. The average sediment transport and spatial distribution of erosion and deposition as a function of the erodibility factor

Based on the results of erosion on the slope of the land, the results of peeling on the slope are obtained for each slope. The average yield and maximum peeling value and sediment buildup can be seen in Table 5.

If it is analysed based on slope, the sloping area (8-15%) has a high peeling rate of 1.8239 tons/ha and high rainfall in the region is rather steep (16-25%) of 2.1207 tons/ha.

Table 5. ED value of each slope classification

Slope Class	Range of slope	Area (Ha)	Average ED (Ton/Ha)
Class 1	< 8%	26,088,3 12	-0.3297
Class 2	8% – 15%	7,390,375	-1.8239
Class 3	16% – 25%	5,448,375	2.1207
Class 4	26% – 45%	3,167,813	-0.3282
Class 5	> 45%	1,416,063	0.1467

Overall, by incorporating the K-factor in the analysis, the spatial pattern of sediment transport capacity reflects the influence of areas with high erosion, and thus sediment flow will have lower values over a wide area across the landscape than having very high values concentrated in a concave areas steep slope. However, because the distribution of soil types is highly correlated with topography, the location is also highly dominated by topography.

The distribution of sedimentation was also analyzed based on various soil type factors with the following results

Table 6. Value of ED each soil type

Jenis Tanah	Teksture	Luas (Ha)	Rata-rata ED (ton.Ha)
Assosiation of Brown Alluvial	Lom Clay	4.076	1.9201
Assosiation of Brown Podsolic	Lom Clay	14.390	- 0.3372
Assosiation of Brown Podsolic	Clay	1.474	2.0519
Assosiation Yelow Podsolic & Hydromorf	Clay	2.802	- 2.2859
Assosiation of	Clay	6.787	- 1.4316

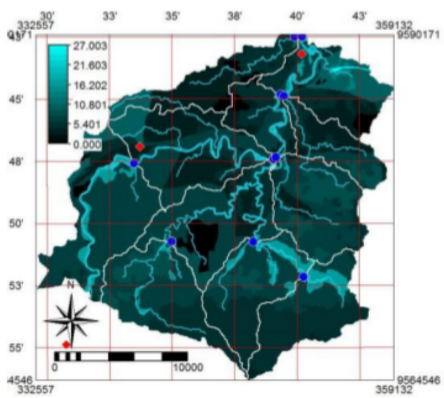

Figure 4, ED each soil type

The spatial distribution of erosion and sediment is also modified by inclusion of soil accessibility patterns in the sense that it increases the area of the area at high risk of erosion.

5. Conclusions

Based on the results of the analysis and discussion above, the following conclusions can be concluded,

- The highest slope erosion potential values are on steep slopes (16-25%) and the largest deposits are on sloping slopes (8-15%).

- Analysis of erosion and deposition rates based on land cover, slope and soil type, showed that the area with the highest peeling in the area of irrigated agricultural land was 2.139 tons / ha / year, on a slope of 1.8239 tons / ha / year.
- Analysis of erosion and deposition rates based on land slope, and soil type, areas with alluvial yellow podsolic soil types, amounting to 2,28591 tons / ha / year. While those with high deposits are found in water areas of 5.2258 tons / ha / year. The area above is rather steep with a spatial distribution of deposition of 2.1207 tons / ha / year. While in areas with brown podsolic and podsolic soil types, the spatial distribution of sediment is 2.05188 tons / ha / year.

6. Acknowledgment

High appreciation to the Institute of Research and Community Services of the University of Sriwijaya, which has provided superior research funding for universities, so that the results of this study could be completed.

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