Spatial Monitoring of Potential Overland Sediment from Significant Land Use Types, for the Remote Contaminated Area of the Mae Tao Basin, Thailand: 15 Years Monitoring Period

K. Somprasong

***Abstract*—The Mae Tao Basin in Mae Sot district, Thailand, is a cadmium contaminated area, where the transcendent media transporter of the contaminant is sediment leached from various surface runoff. The Revised Universal Soil Loss Equation (RUSLE) incorporated with remote sensing and geographic information system (GIS) software were applied to conduct a long-term monitoring of the potential erosion that can be leached out of the significant land use of the Mae Tao Basin from 2002 to 2016. The erosion potential was calculated based on the secondary data from both government and private sectors. The spatial analysis results indicate that high level of potential erosion occurred in the mining production as well as the deciduous forest area of the Mae Tao Basin. In addition, the correlation between the overland sediment and the contamination level in the water system of the basin demonstrates that the sediments from mining production area have the highest correlation to the contamination in the water system of the Mae Tao Basin.**

***Index Terms*—RUSLE, contamination, cadmium GIS, heavy metal, remote sensing.**

I. Introduction

The Mae Tao Basin, defined as the largest zinc deposition area of Thailand, located in Mae Sot district, Tak province. This remote area has been faced the contamination of cadmium which is naturally associated to the occurrence of zinc- composite mineral. The basin was also the location of two zinc mines located in the direction of the main water resource, named as the Mae Tao Creeks which is demonstrates in Fig. 1.

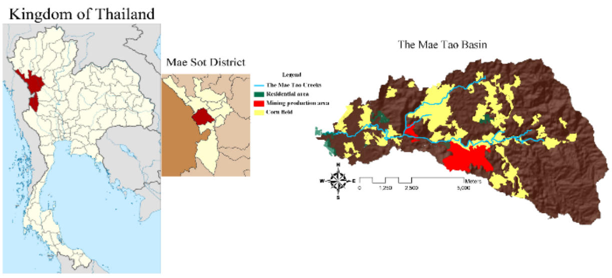

Fig. 1. The location of the Mae Tao Basin.

From 2002, the cadmium contamination incident of the Mae Tao Creek was exposed by the study of [1], the researchers from both government and private sectors have conducted many studies to identify the possible source of cadmium, polluting the basin. [2] reported that the land use alternation within the area can cause some effect to the contamination level of cadmium in the main water resource of the basin, resulting in the dispersion of the contaminant into the downstream of the basin. The contamination over the area of the Mae Tao Basin has been widely spread and were mostly detected to be exeed the acceptable standards [3]. Furthermore, the significant land utilization of the Mae Tao Basin can be classified in 4 major groups as can be seen in Fig. 2.

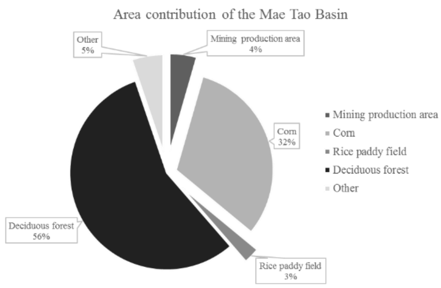

Fig. 2. Significant land use of the Mae Tao Basin.

Rainfall erosion, affected by the land use over the area, was found to be one of the major mechanics that make cadmium available for transport throughout the basin. However, mining procedures and the mine area management have also been blamed for contributing to the problem [3], [4].

Ref. [4] reported that the transportation of the overland sediment was also determined to be one of the transmission intermediate that reinforces contamination level in the basin with the potential flux of erosion at 1.84 ton/ha/year.

Thai Department of Primary Industrial and Mine (DPIM) investigated the area using groups of secondary data and remote sensing technique. The results indicated that the potential in releasing the cadmium contaminant due to rainfall runoff of corn field were found to be as high as the mining production area [3]. Additionally, the effect of land use alternation can cause a slight effect to the sediment transport race in the stream sediment of the Mae Tao Creeks [3].

The Revised Universal Soil Loss Equation (RUSLE) is widely applied as an accommodating equation for estimating surface erosion. By requiring less data and necessitating a short period of time to run, compared to other erosion estimation modelling.

Application of RUSLE is accustomed to the remote sensing for land surveying and development. The integration

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K. Somprasong, is with the Department of Mining and Petroleum Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand (e-mail: komsoon.s@cmu.ac.th).

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between geographic information system (GIS) technology and this erosion models has been proven to be effective at estimating the magnitude and distribution of erosion

Since the land use alternation can possibly cause the effect to the contamination of cadmium in the Mae Tao basin, so the monitoring of the change in land utilization can be use as the indirect indicator of the contamination in the area. This study aims to monitor the change of the land utilization over the past 15 years (2002 to the early of 2016) by applying the integration between Remote sensing technique, GIS application and RUSLE to illustrate the potential erosion that has been change over the study period.

II. METHODOLOGY

The overall framework of the study is established in Fig. 3. The study instigated with data acquisition. For the boundary of the study area, the Mae Tao Basin, covers 6090.75 ha (59.61 km2). The basin contains four significant land utilizations which are mining production areas, corn field, rice paddy fields, and deciduous forest area.

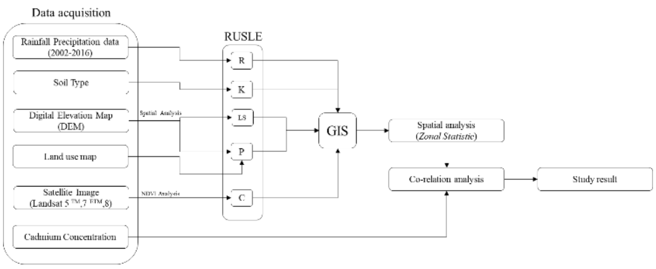

Fig. 3. Methodology framework of the monitoring and estimation.

Daily precipitation data from 2002 to 2016 were gathered from the Thai Meteorological Department (TMD). The soil classified map and land use maps were acquired from the Land Development Department of Thailand (LDD). The Digital Elevation Map (DEM) of the study area was afforded by the Royal Thai Survey Department (RTSD). The satellite image of the basin, covering the study period (2002-2016) were supported by GISTDA. Each set of data was analyzed individually to obtain the values of the required RUSLE parameters. The values were operated by GIS software. The spatial results of each significant land use type from estimation were analyzed in GIS in order to investigate the change in potential erosion per land use type each year.

A. *Revised Universal Soil Loss Equation*

Soil loss or soil erosion refers to the amount of soil moved from one particular area to another in the form of sediment yield. This phenomenon depends on the relationship between raindrops, runoff and the erodibility of a certain area. RUSLE have a capability in estimating of the relentlessness of erosion in the form of quantifiable results by extending the terms of cover management and support practices into the equation.

Since cadmium adsorbed from overland sediment as residue from surface runoff, applying RUSLE to illustrate the potential erosion of the area can reflect the possibility of potential cadmium that can be release into the environmental phases. The Revised Universal Soil Loss Equation is presented in (1).

$$A = R \times K \times LS \times C \times P \quad (1)$$

The R factor is the erosivity by rainfall runoff at a location. The K factor refers to the specific value of the inherent erodibility of the soil surface material at a specific area. The LS reflects the effects of topography, specifically a hill's slope, length, and steepness, on the rates of soil loss at a site. The C factor expresses the effects of surface cover and roughness from the biomass to the rate of soil loss, while the P factor represents effects of soil conservation practices such as buffer strips for cover vegetation.

R factor calculations were conducted base on the study of [5]. The equation was expressed as the linear relationship between rainfall erosivity (R) and total accumulation of rainfall intensity (X) as can be seen in (2).

$$R = 0.4669X - 12.1415 \quad (2)$$

K factor was derived from soil classification map of the Mae Tao Basin are afforded from LDD in association with the study 's result of [6].

C factor values were assigned using classified remotely sensed images. Basically, the classification using NDVI analysis presents a high correlation with ecological variables as leaf-area-index, total vegetation cover or above ground biomass [7]. Researchers developed many methods to estimate C factor using NDVI for soil loss assessment with USLE/RUSLE [8,9,10,11] The unknown C factor values of land cover classes can be estimated using equation obtained from linear regression analyses. The C factor assigned in this study were based on the study of [12] which can present the high accuracy when applied the calculation to the South-East Asia's NDVI analysis. The calculations were performed following (3) to (4)

$$NDVI = (NIR - R)/(NIR + R) \quad (3)$$

$$C = 0.6 - 0.77NDVI \quad (4)$$

where NIR and R indicate channel or band of Landsat which are near infrared and visible red respectively. In this study, the C factor will be derived from the NDVI analysis result of the satellite image from Landsat 5 TM, Landsat 7 ETM and Landsat 8 which can cover the whole monitoring period as can be seen in Table.

The support practice factors (P) were derived from the combination between slope data from the spatial analysis of DEM and land use map based on the criteria, prescribed by [12] The classification of p factor value can be seen in Table I.

TABLE I: P FACTOR USE IN THIS STUDY

Land cover	*P factor*
Agricultural Area with Slope ≤ 8 %	0.5
Agricultural Area with Slope between ≥ 8 % and 20 %	0.75
Agricultural Area with Slope ≥ 20 %	0.9
Shrub, Secondary Forest and Forested Area	0.1

LS-factor calculations were operated under the remote estimation technique using GIS application, following the equation of which is presented in (5). The calculation of LS factor for the surface area of The Mae Tao Basin is presented in Fig. 4.

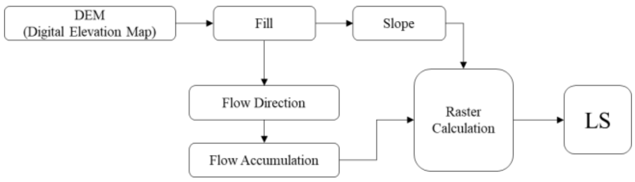

Fig. 4. Methodology framework of the monitoring and estimation.

$$LS = \left(\frac{Flowacc \times resolution}{22.13}\right)^m (65.41\sin^2\theta + 4.56\sin\theta + 0.0654) \quad (5)$$

The LS-factor refers to the surface terrain of the basin and can be obtained by the slope gradient of in the form of percent gradient [13]. The value of m, referred to a coefficient related to the ratio of rill to inter-rill erosion, was varied from 0.2 to 0.5, depending on the slope gradient and m, defined previously, was equivalent to 0.5 for slope > 5 %, 0.4 for slope between 3 %s to5 %, 0.3 for slope range pf 1 % to 3 %, and 0.2 for under 1 % slope.

In a purpose of calculating the flow accumulation, a DEM (30 m resolution) of the basin from the Royal Thai Survey Department (RTSD) was obtained and analyzed under the fill spatial analysis technique to avoid any discontinuity in the flow simulation which can be existed when water is trapped by cells of higher elevation. After that, the flow direction was generated from these filled grids. Flow accumulation was calculated based on the direction acquired from the flow direction analysis. As a final process, the raster calculation was applied to determine the LS-factor.

B. Potential Erosion Estimation and Statistical Analysis

The calculation for potential erosion of the Mae Tao Basin was operated under the spatial analysis for raster calculation in GIS application, based on (1). The potential erosion estimation of the year 2002, 2006,2009, 2012 and 2016, in which the field observation surveying was conducted, were analyzed to represent the major change in land utilization of the Mae Tao basin. By applying the zonal spatial statistical in GIS application, the monitoring of the potential erosion in each significant land used type can be accomplished.

C. Overland Sediment Estimation

Potential erosion estimation's results were assigned into (6) to estimate the overland sediment from each significant land use of the Mae Tao Basin. E_{of} refers to the estimated erosion, whereas $Area_x$ refers to the area of each significant land use type during the monitoring period.

$$E_{of} = A * Area_x \quad (6)$$

D. Correlation Analysis

In correlation analysis, a correlation between two variables can be determined as positive (i.e., higher levels of one variable are associated with higher levels of the other) or negative (i.e., higher levels of one variable are associated with lower levels of the other). The sign of the correlation coefficient indicates the direction of the association. The magnitude of the correlation coefficient indicates the strength of the association. The formula of correlation analysis assigned in this study were expressed in (7). *x* and *y* refers to the inspected variables, assigned for the correlation determination in this study. The overland sediment from each land utilization were analyzed in a purpose of comparing the relationship between the estimated overland sediment and the cadmium contamination in the Mae Tao Creeks.

$$r = \frac{n\sum(xy) - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (7)$$

III. Results and Discussion

A. R Factor Determination

R-factor calculation result. Applying the (1), the rainfall runoff value of the Mae Tao Basin from 2002- 2016 were assigned and the calculation's result are established in Table II. The value of R factor, retrieved from the calculation, were in the same range except the R value of the year 2012, in which the great flood incident took place.

TABLE II: R Facter Assigned in This Study

Year	***Rainfall erosivity: R (MJ mm ha^{-1} h^{-1})***
2002	1908.0
2004	1753.6
2006	1797.9
2009	1734.5
2012	2052.6
2016	1536.6

B. K Factor Determination

The calculation layer of K factor is established in Fig. 5.

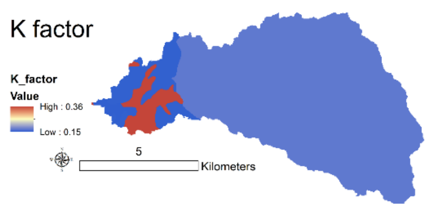

Fig. 5. K factor's evaluation result.

C. C Factor Determination

GIS application was assigned as a main tool to illustrate the calculation layer of C factors. The calculation layers of C factor in the monitoring years are demonstrated in Fig. 6. According to the remote sensing results, the high C factor (0.9-1) were mostly sensed during 2002 when the first existence of cadmium contamination in the Mae Tao Basin area were detected.

D. P Factor Determination

The land use maps of 2002, 2006, 2012 and 2016 were classified based on their feature as bare soil area, agricultural area, forestall area and other land utilization type. These sets of data will be calculated in association with the raster calculation layer of the slope, calculated by DEM, to illustrate the P factor calculation layer of in year in GIS application as can be followed in Fig. 7.

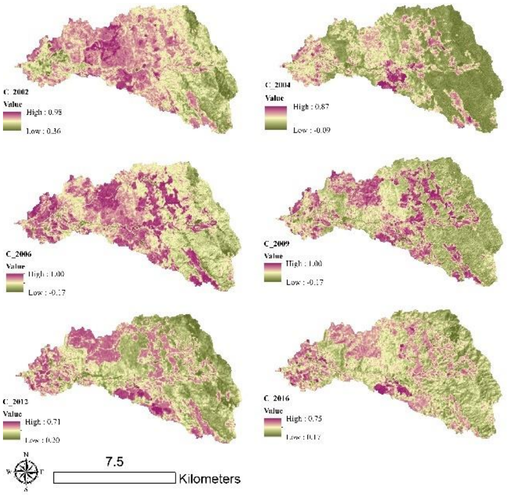

Fig. 6. C factor's evaluation results.

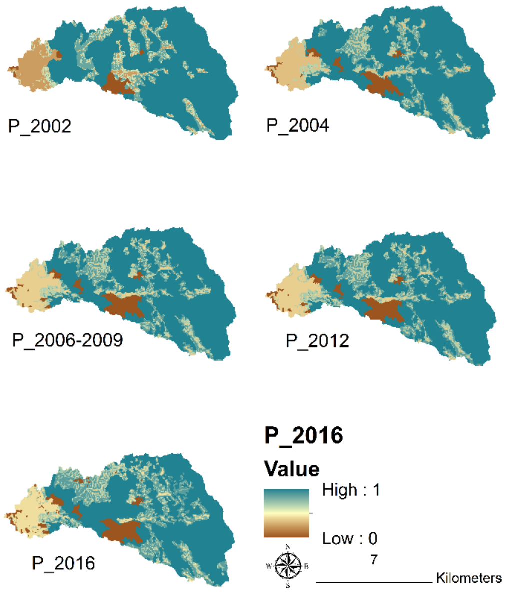

Fig. 7. P factor's evaluation results.

E. LS Factor Determination

LS-factor calculation results. Fig. 8 exhibits the calculations of LS factor from the DEM of the Mae Tao Basin. More than assigned as the input of percent slope calculation layer, DEM was transformed to illustrate the flow direction layer and flow accumulation of the project area. These layers were combined with the raster calculation to retrieve the LS factor calculation layer.

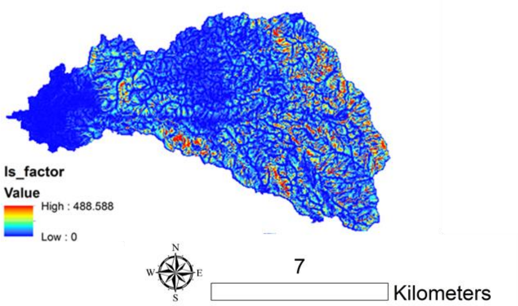

Fig. 8. LS factor's evaluation result.

F. Potential Erosion Estimation Results

According to the estimation result from RUSLE, the potential erosion of the Mae Tao Basin area each year are demonstrated in Fig. 9 and Table III.

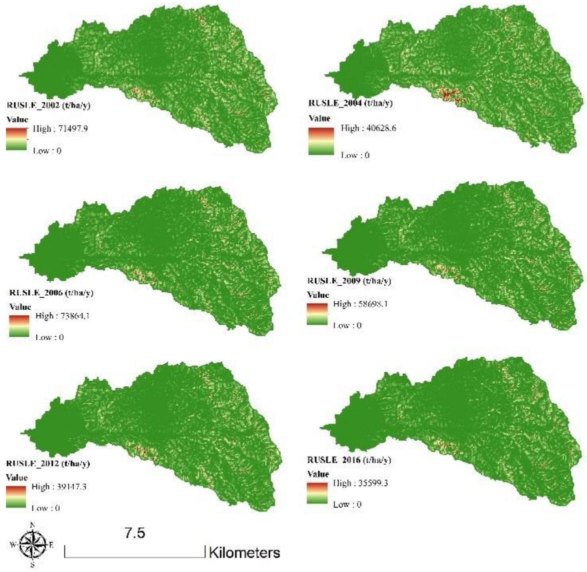

Fig. 9. Potential erosion estimation's result.

TABLE III: POTENTIAL EROSION ESTIMATION'S RESULT

	Potential erosion (t/ha/y)		
year	**Minimum**	**Maximum**	**Average**
2002	0	71497.92	1425.63
2004	0	40628.58	511.04
2006	0	73864.12	1523.75
2009	0	58698.1	1315.06
2012	0	39147.32	852.73
2016	0	35599.28	641.57

According to the result of the estimation, the high surface erosion rate can be occurred in the eastern area of the Mae Tao Basin. Due to high differences in elevation. The highest potential erosion. The highest potential erosion of the basin was determined to be 73864.12 t/ha/y in 2006, while the lowest value of the results was equal to zero each year.

The results from Table5 indicates the fluctuation in the potential erosion that can be occurred during the monitoring years. After the disclosure of cadmium contamination in 2002, the government established many contamination remediation and protection plan including the encouragement of the residents for reforestation and selective vegetation resulting in the reduction of the potential erosion of the area.

The average potential erosion of the entire Mae Tao basin reduced from 1425.63 t/ha/y to 511.04 t/ha/y. However, during the flood incident after drought in 2006, the average potential erosion of the basin raised up to 1523.75 t/ha/y due to the high intensity of precipitation. This is the evidence that high precipitation rate is the important factor that initiate the high erosion in the Mae Tao basin area.

Table IV demonstrates a potential erosion of the significant land use of the Mae Tao basin area. The monitoring result indicates that the change in potential erosion of each significant land use follows the same trend as the whole basin. The high potential erosion rate is mostly sensed around the deciduous forest of the Mae Tao Basin area range from 503.32 to 1898.66 t/ha/y. Corn field, located at the highland of the basin, contains potential erosion range from 431.60 to 1132.77 t/ha/y while rice paddy field has the lowest range of the potential erosion from 62.77 to 268.78 t/ha/y.

TABLE IV: POTENTIAL EROSION OF SIGNIFICANT LAND USE TYPE OF THE MAE TAO BASIN

	Potential erosion (t/ha/y)				
Year	**Rice**	**Corn**	**Forest**	**Mine**	**Average**
2002	62.77	798.95	1898.66	3981.73	1425.63
2004	88.82	494.33	503.32	1923.22	511.04
2006	190.84	1132.77	1857.72	2639.91	1523.75
2009	173.50	997.29	1583.45	2371.46	1315.06
2012	258.34	628.50	1018.31	1589.28	852.73
2016	262.78	431.60	783.79	1233.26	641.57

Mining Production area has been continuously sensed as the highest potential area that can release the overland sediment. According to the open cast mining technique of this zinc mine, the surface of the production area was removed as the over burden, causing the area to be a large human-made cliff with no cover practice. The potential erosion of the mining production area ranges from 1589.28 to 3981.73 t/ha/y.

G. Overland Sediment Estimation Result

TABLE V: ESTIMATED EROSION'S RESULT

	Estimated erosion (10^6t)				
year	**Rice**	**Corn**	**Forest**	**Mine**	**Basin**
2002	0.026	0.753	7.973	0.588	8.682
2004	0.029	0.661	1.995	0.366	3.117
2006	0.051	1.634	6.424	0.653	9.282
2009	0.046	1.447	5.484	0.593	8.011
2012	0.042	0.950	3.482	0.397	5.193
2016	0.034	0.829	2.435	0.334	3.918

Table V demonstrates the results of the overland sediment estimation from each significant land utilizations. From 2002 to 2016, the potential erosion of each significant land use in the Mae Tao Basin have been demonstrated the same trend. Since 2002, when the contamination in the Mae Tao Creeks was disclosure, the remediation and protection plan were released in a purpose of preventing further environmental impact to the residents at the downstream. The reforestation and subsidizing of rice paddy field to other crop such as cassava and corn for livestock feeding were conduct, resulting in the sharply reduction of the potential erosion in 2004.During 2006, the potential erosion of every significant land use was continuously increase due to the high precipitation rate in the area of the Mae Tao Basin.

According to the estimation results, deciduous forest is the significant land use that can release the highest number of erosion sediment at 7.973 $\times 10^6$ ton in 2002. Despite the fact that the mining production area contains the highest potential erosion, but the area of the mine in the Mae Tao Basin covers only 4.4% of the area contribution, making its estimated sediment share a smaller portion than the sediment from both deciduous forest and corn field area.Overland sediments, released from mining production area ranges from 0.334 to 0.593 $\times$ 10^6 ton. Figure demonstrates the sediment contribution of each land use type over the basin.

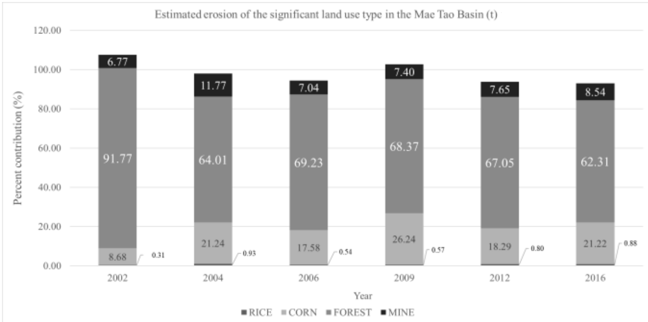

Fig. 10. Contribution of overland sediment from significant land use of the Mae Tao Basin.

According to Fig. 10 , the land use type in which highest surface sediment can be eroded were determined to be the deciduous forest which is range from to 67.05% 91.77% of the overall sediment from erosion..

The eroded sediment from mining production shares only 6.77% to 11.77% of total overland sediment during the eaily years of the montitoring, while the sediments from corn field shares 8.68% to 21.22% of the area utilization. As a result of greater coverage area than the mining production's, corn field have a higher capacity in releasing the erosion sediment into the environmental phase of the Mae Tao Basin area. The highest potential erosion.

Moreover, the estimation indicates that the erosion from the rice paddy field share the smallest portion of the erosion sediment. Rice paddy field, mostly locates at the downstream of the basin shares only 0.31% to 0.80% of the overall sediment.

H. Correlation Analysis Result

The overland sediment from each land utilization were analyzed in association with cadmium contamination level in the Mae Tao Creeks as can be seen in Table VI. These records of the contamination were retrieved from the secondary data as the average cadmium concentration in during the monitoring years.

TABLE VI: TABLE TYPE STYLES

Year	*Cadmium concentration (mg/kg)*
2002	367.00
2004	102.50
2006	687.50
2009	142.00
2012	62.02
2016	32.50

TABLE VII: TABLE TYPE STYLES

Land use type	*R(E)*
Rice	0.40
Corn	0.60
Forest	0.72
Mine	0.81
Basin	0.78

Table VII demonstrates the correlation analysis' results. The analysis result indicates that overland sediment eroded from the mining production area has the highest positive relationship among the others at 0.81. Additionally, the correlation of the corn field and deciduous forest demonstrate the same range of the relationship towards to the contamination in the stream sediment of the Mae Tao Creeks at 0.60 and 0.72 repectively.Nevertheless, rice paddy field, scattered around the downstream of the Mae Tao Basin, has the lowest corelation factor at 0.40.

I. Discussion and Suggestion

According to the co-relation analysis results, erosion from mining production area contain the highest correlation factor. Containing the highest value of correlation factor, the change in potential erosion of the mining production area can strongly stimulus the contamination in the creeks. Because of the lack of sufficient land cover management, the total erosion was amplified by the overall steepness of the bench, resulting in high LS factor in the estimation. Since the large volume of erosion can be occurred in the mining activity area, the preventive practice such as the plantation of vetiver grass or other deep roots plant on the high slope area and the providing of effective sediment pound should be integrated.

Even supposing that the high potential erosion rate was mostly sensed around the deciduous forest and the erosion from this area performed a high correlation to the contamination, there are some natural deposition processes that have a capability in reducing erosion within the area. This process also probably diminishes the chance in transporting the overland sediment into the creeks. However, erosion, from the highland area, must be continuously monitored due to highland's sediment availability that can influence the chance in cadmium contamination

Moreover, the erosion from the rice paddy field has been continuously increased, then further study for monitoring of the erosion trend, especially in the downstream of the basin to the creeks must be closely conducted Rice paddy field, densely located in the downstream of the basin, have the lowest correlation to the contamination, however; the contamination of cadmium in the rice paddy field can cause a chronic effect to the consumer of rice product, so that the expansion of rice paddy field should be limited and subsidized by other crop such as cassava for energy production.

Nevertheless, subsidizing of rice paddy field into corn field can increase sediment availability. The corn field, possesses greater correlation factor than rice paddy field, has been largely expanded during the study period. [2,4] reported that the potential cadmium flux from erosion of the corn field area in the Mae Tao Basin were as high as the potential from the mining production area so that the subsidizing of both highland rice paddy field and deciduous forest with the crop field, which contain a low resistivity to the erosion, can stimulus cadmium contamination level in the creeks. According to this characteristic, the deforestation for agricultural aspect, especially corn field expansion, in the Mae Tao Basin area should be strictly prohibited.

IV. Conclusion

In summary, this integrated method between RUSLE, GIS, and remote sensing can effectively be assigned to classified the potential erosion of land use type in the remote area. The results of the study explicate the change of potential erosion, varied by time and area of the land use type with the purpose of realizing the capability in releasing one of the possible source of the contamination media in the Mae Tao Basin area. The comparison of the sediment-releasing capability can be conduct even remote areas such as thick forests or unreachable valleys can be evaluated. Additionally, this study has also revealed the capability of customizing this integrated method to be utilized in other similar contaminated site for a rough estimation of the remote area.

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K. Somprasong was born in on 16th February 1984. He graduated with the bachelor's degree and the master's degree in georesources engineering from the Department of Mining and Petroleum Engineering, Faculty of Engineering, Chulalongkorn University in 2006 and 2009 respectively.

He was once an executive officer of planning and development of the Democrat Party of Thailand. Thereafter, he has carried out this research as a part of studied for the Doctoral degree in Environmental Management at graduate school, Chulalongkorn University under the management of Center of Excellence on Hazardous Substance Management. He is currently a lecturer at the

Department of Mining and Petroleum Engineering, Faculty of Engineering Chiang Mai University.

Dr. Komsoon Somprasong is now working on the spatial contamination analysis of contaminants in mining production area with a publication entile "Estimation of potential cadmium contamination using an integrated RUSLE, GIS and remote sensing technique in a remote watershed area: a case study of the Mae Tao Basin, Thailand in Environmental Earth Sciences.