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Application of integrated spatial approaches for studying the vegetation alternation's effect on the reclaimed land of contaminated zinc mine

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Application of integrated spatial approaches for studying the vegetation alternation's effect on the reclaimed land of contaminated zinc mine

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Abstract. The Mae Tao basin, Thailand has been considered to be a remote cadmium (Cd) - contaminated area since 2002. This area has been reported as the largest zinc deposition area so that the explicit potential cadmium source has not been detected. According to the reports from both government and private sectors, the zinc mine in the middle of the basin were determined to be one of the cadmium contributors in the area. From 2014, the mine closure operation has been conducted, thus the study on the selection of cover vegetation in the area has not been accomplished. In this study, the integrated approaches between MINESITE 3D, Geographic Information System (GIS) application and remote sensing techniques, were assigned to simulate the repetition of the vegetation over the reclaimed area. The study demonstrates that using the grass type vegetation for the reclamation of the area can largely reduce the potential erosion of the mine with a range from 89.70 to 94.45%. The results also demonstrate that the young vetiver grass cannot effectively reduce the potential erosion. Additionally, the study on the development of the supporting practice over the mining production area should be further conduct.

1. Introduction

Mine contaminated sediment has been determined to be one of the cadmium contributors which contaminated the Mae Tao Basin area. Padaeng zinc mine, Tak province were discovered to be the accumulated area and the one of the contributors of cadmium contaminants. Total Cd and Zn concentrations in sediments or soils were approximately 596 and 20,673 mg kg^{-1} in tailing pond area, 543 and 20,272 mg kg^{-1} in open pit area, 894 and 31,319 mg kg^{-1} in stockpile [1]. This mine is located in a remote area of the Mae Tao Basin which has been facing this contaminated case since 2002 [2][3]. Figure 1 demonstrates the location of the mine.

Overland sediment, takes place during rainfall runoff over the contaminated zinc-cadmium deposition area in the mine, was found to be one of the transmission intermediates reinforcing the contamination level [4]. [5] reported that the land use rotation in the basin can cause effects to the contamination level of cadmium in the creeks. This incident is affected by the mechanism of rainfall erosion over each land cover type which results in the spreading of cadmium contaminants throughout the basin.

Furthermore, the contamination in the basin were discovered to be related to the change in mining production area. Rainfall erosion, affected by the slope and land cover of the area, was discovered to be one of the major mechanics that make cadmium available for transport in form of adsorbed-suspended sediment [6]. Additionally, erosion, took places in the mine, can be related to the contamination in the Mae Tao Creek. With a correlation factor at 0.81, this mining production area were one of the main contributors of the contaminants [7].

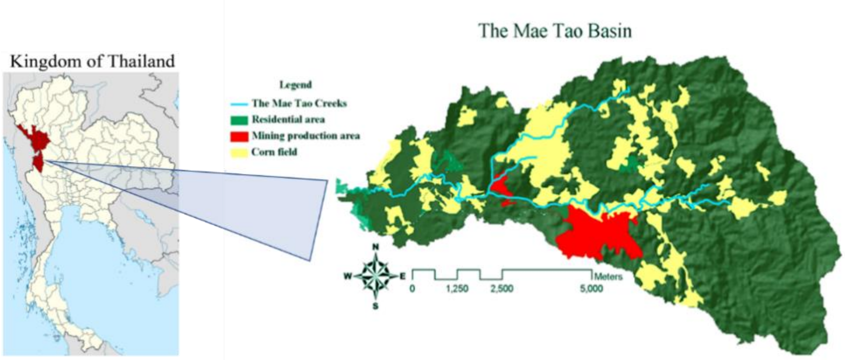

Figure 1. The location of the mine (labelled as red area)

Since 2014, the operation plan in reclamation of the mining production area has been established, thus the expected results in the reduction of the erosion that can be released from the mining production area has not been disseminated.

This study aims to examine the effect of the land use alternation over the reclaimed land of the mining production area. Since changing in land use refers to changes in land cover practices, the integrated spatial techniques between Revised Universal Soil Loss Equation (RUSLE) accustomed to the remote sensing technique and geographic information system (GIS) technology were applied to simulate the change in the potential erosion of the reclaimed mine. This integrated method has been proved to be the effective approach for estimating the magnitude and distribution of erosion practice [4][8]. It also widely applied as an accommodating equation to estimate surface erosion and it requires a fewer data and a shorter period of time to complete the evaluation compared to other erosion estimations [8]. By the advantages of this integrated approaches, the efficiency in reduction of the potential erosion can be clarified, leading to the appropriate selection of cover practices in the reclamation's operation.

2. Methodology

The overall framework of the study is established in figure 2. The study instigated with data acquisition. The secondary data from various sources were gathered and assigned as the RUSLE 's inputs. R factor was calculated using 50 years data from Thai Meteorological Department (TMD). Satellite images during 2002 to 2016 from LANDSATTM and soil type map of the study area were assigned as the inputs for the calculation of C and K Factors, respectively. The Digital Elevation Map of the mining production area was remodeled, using the integration between the MINESITE 3D and Computer Aided Design and Drafting (CAD) application. Afterward, 13 alternation-scenarios of land cover types were simulated to compare the efficiency in the reduction of potential erosion of the study area.

2.1. Data acquisition

Daily precipitation data from 2002 to 2016 were obtained from the Thai Meteorological Department (TMD). The soil classified map was supported by the Land Development Department of Thailand (LDD). The Digital Elevation Map (DEM) of the study area was acquired by the Royal Thai Survey Department (RTSD). The LANDSATTM 's satellite image of the basin, covering the study period from 2002-2016 were afforded by GISTDA.

2.2. *Revised Universal Soil Loss Equation*

Soil loss or soil erosion means that the amount of soil moved from one area to another. This phenomenon is based on the relationship between raindrops, runoff and the erodibility of a certain area. RUSLE can quantify the erosion amount by extending cover management and support practices terms into the equation. Since cadmium, contaminated in the basin adsorb with the overland sediment as residue from surface runoff [4], so the RUSLE can illustrate the potential erosion of the area, reflecting as the possibility of the cadmium that can be released into the environmental phases. The Revised Universal Soil Loss Equation is expressed as (1)

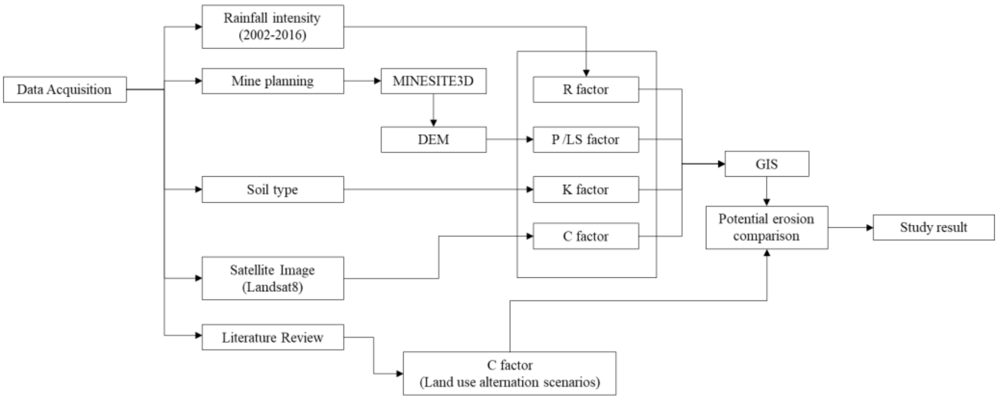

Figure 2. Overall framework of the study

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

The R factor refers to the erosivity causing by rainfall runoff at a location. The K factor is the specific value of the inherent erodibility of the soil surface material at a specific area. The LS is the representative value of topography's effects from 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 [4].

2.3. *R factor*

R factor calculations were conducted base on the study of [9]. 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).

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

2.4. K factor

K factor was derived from soil classification map of the Mae Tao Basin, evaluated by the study 's result of Somprasong (et.al,2015).

2.5. C factor

Researchers established many methods [10] [11] [12] [13] to estimate C factor. One of the effective procedures is the using of classified remotely sensed images under the linear relationship of the ecological variables as leaf-area-index, total vegetation cover or aboveground biomass [14] and their NDVI index, according to their high correlation. The C factor assigned in this study was based on the study of [15] which can present the high accuracy when applied the calculation to South-East Asia's NDVI analysis. The calculations were performed following (3) to (4)

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

$$C = 0.6 - 0.77\,NDVI \tag{4}$$

where NIR and R indicate channel or band of Landsat which are near-infrared and visible red respectively. C factor will be derived from the NDVI analysis result of the satellite image, taken by Landsat 8.

2.6. P factor

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 [16]. The classification of p factor value can be seen in table 1. DEM applied in this study were separately retrieved by two sources. One was supported by RTSD and another was remodelled by MINESITE 3D application. Figure 3 demonstrates a process in the remodelling of DEM from mining production area. The process begins with the gathering of the mine planning data which were used as references for the elevation of the area. Afterward, the elevation data were drafted as the 3-dimension model in the application. This model is usually applied as the planning tools for material extraction planning with high accuracy of the interpolation so that the missing elevation can be fulfilled. The 3-dimension model was then exported as a shapefile of contour and further converted into DEM using GIS application.

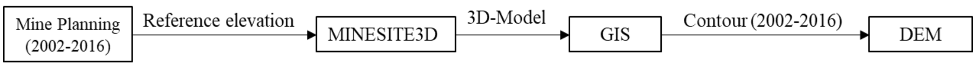

Figure 3. Remodelling of mine's DEM

Table 1. P factor assigned as the data input for GIS' calculation layer

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

2.7. LS factor

LS-factor calculations were carried out using a GIS application based on the equation presented in (5). The calculation of LS factor for the surface area of The Mae Tao Basin is presented in Figure 4.

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

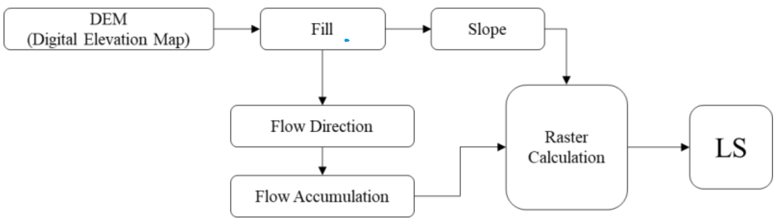

Figure 4. Calculation method for retrieving the LS factor

The LS-factor reflects surface terrain of the basin and can be illustrated as an input layer by transformation of the slope gradient [17]. 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 of 1 % to 3 %, and 0.2 for under 1 % slope.
In this study, the flow accumulation was obtained using a 30 m resolution DEM from the Royal Thai Survey Department (RTSD). The layer was analyzed under spatial analysis function. Fill command were assigned to avoid any discontinuity in the flow simulation which can be existed when water is trapped by cells of higher elevation. Afterward, the flow direction was generated from these filled grids. Flow accumulation was calculated based on the direction acquired from the previous process and the raster calculation was applied using those layers to determine the LS-factor.

2.8. Cover practice alternation simulation

In a purpose of comparing the effectiveness of reducing the potential erosion of the mine, 13 different values of cover practice factor (C) were assigned as the data input in RUSLE. Table 2 demonstrates the value applied in this study [18] [19]. The land cover practice, applied in this study, were selected based on the regular land use, appeared in the Mae Tao Basin such as corn, soybean, paddy field and cassava. This selection has a tendency to simulate the utilization of the reclaimed land for agricultural aspects.

Table 2. C factor applied in the simulation of land use alternation.

Land use type	**C factor**
Grass plants (Brachiaria sp)	0.290
Bean	0.161
Cassava	0.363
Lemongrass	0.434
Hardwood with scrub	0.012
Perennial grass	0.020
Forrest	0.001
Overlapped cropping and straw mulch	0.079
Sequential cropping and crop residue mulching	0.347
Sequential cropping pattern	0.398
Overlapped cropping and mulch of crop residue	0.357
Vetiver (earlier state)	0.350
Vetiver (aged)	0.037

3. Results and discussion

3.1. R factor calculation's result

The rainfall runoff value of the Mae Tao Basin from 1998 - 2016 were assigned.The value of R factor, retrieved from the calculation, were equal to 703.22 MJ mm ha^{-1} h^{-1}

3.2. K factor determination's result

Secondary data on the land use of the Mae Tao Basin from LDD were assigned into GIS calculation layer as can be seen in figure 5.

3.3. C factor determination's result

GIS application was assigned as a main tool to illustrate the calculation layer of C factors. Figure 6 and 7 demonstrates the results of NDVI analysis. The calculation was conduct using the large boundary of the basin and then extracted using spatial analysis

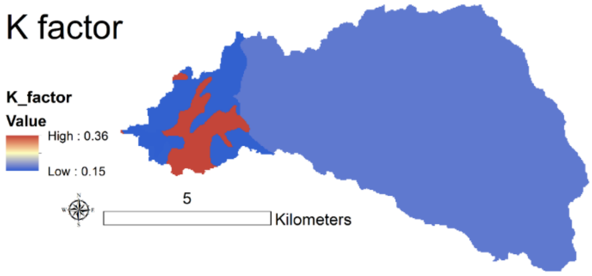

Figure 5. K factor's evaluation result

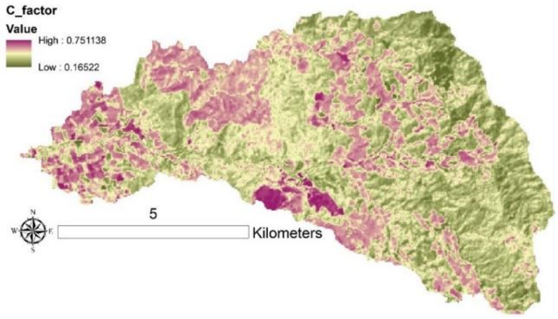

Figure 6. C factor's evaluation result

3.4. DEM remodeling's results

The DEM of the mine were remodeled in order to improve the accuracy in the estimation of the potential erosion in the mine. Figure 7 demonstrates the remodeled- DEM of Padaeng zinc mine, based on the mine planning in 2016 Consistent with the remodeling the missing elevation model in the southern part of the mine were figured so that the estimation of the runoff sediment can be more extensive.

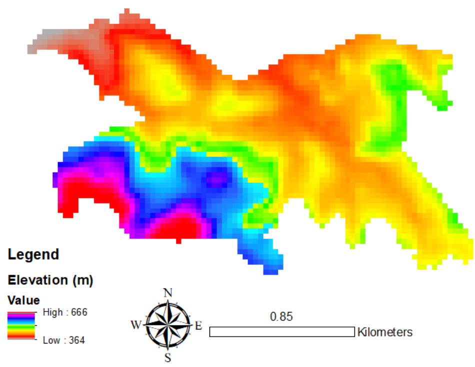

Figure 7. DEM of the mine from the remodelling process

3.5. LS factor calculation's results

Figure 8 exhibits the calculations of LS factor from the remodeled- DEM of the mine. 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.

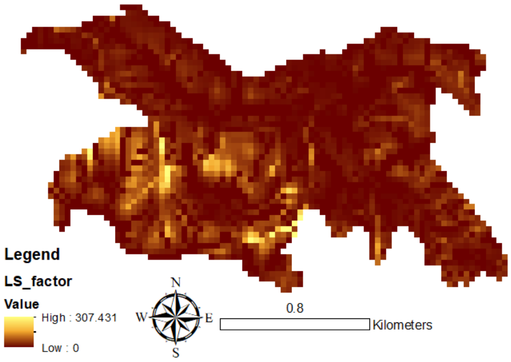

Figure 8. LS factor calculation factor of the mine

3.6. Potential erosion estimation results .

The highest value of potential erosion was found in the southern part of the mine which is the location of the previous production areas as can be seen in Figure. The highest magnitude of the potential erosion was detected to be 16.14 ± 1.24 x10^3 t/ha/y as can be seen in figure 9.

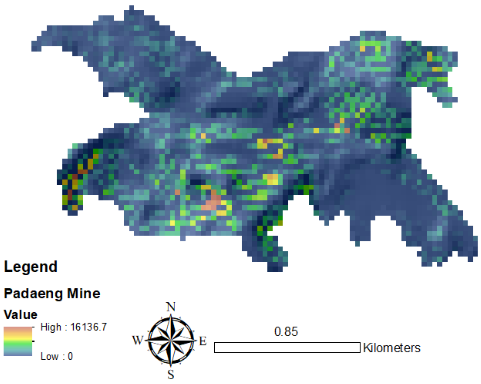

Figure 9. Potential erosion estimation' results of the mine

Table 3 Simulation results of the land use alternation

Land use type	Maximum potential erosion (t/ha/y)	Erosion reduction efficiency (%)
Grass plants (Brachiaria sp)	9696.61	39.91
Bean	5215.11	67.68
Cassava	7838.36	51.43
Lemongrass	14058.51	12.88
Agroforestry	538.47	96.66
Perennial grass	897.45	94.44
Forrest	44.87	99.72
Overlapped cropping and straw mulch	3544.94	78.03
Sequential cropping and crop residue mulching	15570.80	3.51
Sequential cropping pattern	17859.30	-10.68
Overlapped cropping and mulch of crop residue	8974.54	44.38
Vetiver (earlier state)	16602.90	-2.89
Vetiver (aged)	1662.09	89.70

3.7. Land use alternation simulation's results and discussion

Thirteen variations of land utilization and practices were applied and converted into raster calculation layer of c factor to simulate the changes in potential erosion in the mine. Table 3 demonstrates the results from the repetition of the land use over the mining production area.

The results express that changing in land cover practice over the mine surface can effectively reduce the estimated potential erosion. Consistent with the simulation results, changing the land use type into deciduous forest which has the highest efficiency in reducing the potential erosion can reduce the potential erosion of the mine area from 16136.68 t/ha/y to 44.87 t/ha/y or 99.72%.

Perennial grass, currently applied as the cover practice in some area of the mine can reduce 94.43% of potential erosion, while mixed shrub and perennial tree can enhance the efficiency of the reduction to 96.66%.Furthermore, vetiver grass, considered to be effective in reducing rainfall erosion by many studies, cannot effectively applied as the cover practice for the study area due to its low erosion resistivity at the young age. Applying vetiver grass as land cover can effectively reduce the potential erosion after 10 years of plantation with % reduction of 89.70 %.

Agricultural crops contain lower effectiveness in the reduction of potential erosion. Corn, densely vegetated in the surroundings of mining production area, can moderately reduce the potential erosion at 61.23%, while cassava and bean can slightly decrease the erosion at 51.42 and 67.68 % respectively. Figure 10 demonstrates the diagram, comparing between reduction efficiency of each land use type and cover practice.

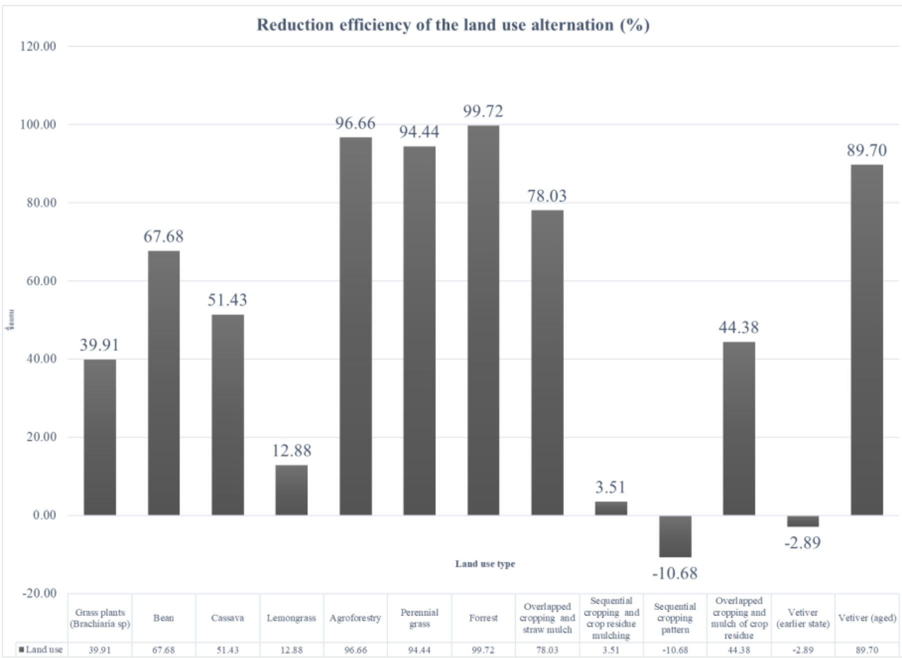

Figure 10. Simulation's result of land use alternation over the mine area

Mining production area has been continuously sensed as the highest potential area that can release the overland sediment [7]. Due to the open cast mining technique, the surface of the mine has been removed as the overburden, causing the area to be a large human-made cliff with high erosion rate. Because of the lack of enough 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 occur 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. The simulation on the repetition of land cover practice were conduct in order to compare this preventive plantation which can be use as the alternatives in the protection of eroded-contaminated sediment over the reclaimed mine.

Agroforestry couple with plantation management, possessing a capability in increasing of erosion resistivity of the agricultural crop [21], can be a key in the adaptation of the study area for agricultural aspects. According to the study's results, changing of previous mine surface with this integrated plant can enhanced the reduction efficiency. Overlapped cropping, covered by straw mulch can reduce 78.03% of the base potential erosion, while the mixing plantation between hardwood plant and shrub can reduce 96.60%. Even supposing that the erosion resistivity of the agricultural crop can be improved, thus some of the plantation management cannot successfully reduce the high potential erosion of the area as can be seen from the simulation results of the sequential cropping pattern which shows the efficiency of the reduction at -10.68%.
Despite the fact that the agricultural vegetation can be applied in the mining production area, thus the implantation of the crops in this area cannot be succeed. Since, mining pit is that lack of topsoil which can provide the enough nutrients for plant growth so the vegetation over this area cannot effectively yield the crops' product. Furthermore, the risk in contaminating of cadmium can make the products inconsumable.
As suggestions, the selection of land utilization for the reclamation over the ex-mining production area should be focus on the growth period of the plant. Because of the potential of the area that can carry on spreading the contaminant into the environmental phases, rapidly-growth plant can reduce the chance in the contacting between rainfall runoff and the bare surface of the production area. Grass plant, enriched with root system, can preserve the soil surface due to their high erosion resistivity. However, at the earlier state, cover material and plantation techniques should be used to enhance the efficiency of the reduction.
Agroforestry can be one of the alternatives in the reclamation of the mining production area. The combination between perennial tree and shrub were demonstrated to be the most appropriate land use that can response to every aspects of the land utilization. Perennial tree, contain an ability in reducing of rainfall intensity and erosivity can decrease the magnitude of R factor, resulting in the influencing of the erosion reduction of shrubs at the lower area. Additionally, alternating the study area in food crops such as corn and rice paddy filed are strictly prohibit due to their capability in the recontamination of cadmium from the soil into the food chain.

4. Conclusion

In summary, this integrated spatial approaches, consists of RUSLE, GIS, remote sensing and can be successfully assigned to estimate the potential erosion in the mine. In association with CAD and MINESITE 3D application, the remodelled DEM of the mine can explicate the better description on the topography of the mining production area for better efficiency in the simulation of the change in potential erosion for unique land utilizations. The process can be enhanced into a powerful tool in supporting of selecting the land use type of the reclaimed land. According to this integrated approach agroforestry was considered to be the most appropriated land use type that can response to every aspects of the land utilization. In addition, this study has also revealed the capability of customizing this integrated method to be utilized in other similar reclamation case.

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