Journal of Natural Resources and Environmental Management
12(1): 82-96. http://dx.doi.org/10.29244/jpsl.12.1.82-96
E-ISSN: 2460-5824
http://journal.ipb.ac.id/index.php/jpsl

Analysis of erosion management based on GeoWEPP Spatial Modeling on bauxite mining activities PT XYZ in West Borneo

Rika Setiabudi Santoso[a], Sri Mulatsih[a], Yudi Setiawan[bc]

[a] Natural Resources and Environmental Management Study Program, Graduate School, IPB University, IPB Baranangsiang Campus, Bogor, 16127, Indonesia [+62 82243398999]
[b] Department of Forest Resource Conservation and Ecotourism, Faculty of Forestry and Environment, IPB University, IPB Dramaga Campus, Bogor, 16680, Indonesia
[c] Environmental Research Center, IPB University, IPB Dramaga Campus, Bogor, 16680, Indonesia

Article Info:
Received: 13 - 12 - 2021
Accepted: 17 - 01 - 2022

Keywords:
Erosion, bauxite, GeoWEPP, sediment, settling pond

Corresponding Author:
Rika Setiabudi Santoso
Natural Resources and Environmental Management Study Program, Graduate School, IPB University;
Tel. +6282243398999
Email:
santosores87@gmail.com

Abstract*. Bauxite ore open-pit mining activities are conducted in spread areas and increase the potential for water pollution, implying a need for good management. GeoWEPP is a spatial model that predicts the erosion magnitude and the location of sedimentation. This helps in erosion management and control, including constructing a settling pond. Therefore, the purpose of this study was to examine GeoWEPP based on land use, topographic and soil maps, as well as rainfall, and temperature data, then modeled with the GeoWEPP application. GeoWEPP simulation calculations are carried out only at the operational stage of mining activities. The map of the mining activity area in land use is a simulation of the planned activity area obtained from the EIA Document. The results showed that 30 Block/Hills with a total area of 13 602.48 ha obtained sediment of 150 186 m^3/month and the amount of runoff of 4 202 267 m^3/month. Furthermore, GeoWEPP analysis on the planned mining block area obtained 30 outlet points to be used as the location for the settling pond construction. All erosion and sedimentation calculations are simulations of the GeoWEPP application and are not validated with measurements in the field. The optimistic and pessimistic cost of constructing the entire settling pond is Rp 196 585 791 231 and Rp 222 773 049 768, respectively. Additionally, the cost of settling pond maintenance at all outlet points during operation is Rp 3 139 414 818. Planting cover crops in ex-mining areas effectively reduce erosion by 0.02 Ton/Ha/Year during the cover crop growth and maturity, respectively.*

How to cite (CSE Style 8th Edition):
Santoso RS, Mulatsih S, Setiawan Y. 2022. Analysis of erosion management based on GeoWEPP Spatial Modeling on bauxite mining activities PT XYZ in West Borneo. JPSL **12**(1): 82-96. http://dx.doi.org/10.29244/jpsl.12.1.82-96.

INTRODUCTION

Mining is an important source of state revenue but also contributes to environmental damage. Mining's positive contributions include state revenues such as taxes and PNBP, generating other sectors, and creating job opportunities. The negative impacts include open-pit mining activities that reduce land cover, impacting the hydrological system by increasing evapotranspiration and soil erosion, and decreasing water storage (Anwar *et al.*, 2011). One activity that applies the open-pit method is Bauxite mining. Bauxite is a metal mineral mining material used as raw material for Aluminum, one of the favorite commodities. This is in line with the growing domestic Bauxite mineral downstream program. Bauxite mineral characteristics are generally found in small hills and overburden depths of 0-2 meters and ore with varying thicknesses between 1-10 meters. It is generally located on a large expanse of land (IAI, 2018). Before carrying out Bauxite mining, the land is cleared and the overburden excavated.

The potential Bauxite resources and reserves in Indonesia are located on Bintan, Riau, Bangka, Kalimantan, and Sulawesi Islands, as well as Halmahera. West Kalimantan Province has the largest potential with 57.32% resources and 66.77% reserves of the total Bauxite in Indonesia, which is divided into nine districts, including Ketapang Regency (Pusdatin ESDM, 2016). PT XYZ is the largest Bauxite mineral mining company in Ketapang Regency with several Mine Area Permits (IUP), including IUP in 24 700 hectare (ha) in Sandai and Sungai Laur Sub-districts. The mining area is located upstream of Pawan Watershed (DAS), and most estuaries flow towards Pawan River. Pawan is the longest (±197 KM) and widest (±11 202 KM^2) river, which empties Ketapang Regency and is used by the community for daily activities.

Companies must implement good mining practices, including managing the mining environment. Appropriate environmental management and conservation are needed to prevent water quality and soil degradation (Kamble and Bhosale, 2019a). Changes in land use and cover result in land degradation and water quality (Defersha *et al*., 2012). Areas of active and ex-mining pit openings on a large expanse might trigger mine erosion and pollute water areas. Every mining activity in Indonesia needs to apply good practices, which are in line with the mandate of Article 95 letter a and Article 96 of Law number 4 of 2009 concerning mineral and coal mining. According to Maalim *et al.* (2013), land cover changes greatly affect the amount of runoff. At a slope of 8-15% has an erosion rate between 1 023.57-1 194.16 tons/ha/year and at a slope of 0-8% between 163.49-199.03 tons/ha/year (Suherman *et al*., 2015). Therefore, Regulation of the State Minister of the Environment Number 34 of 2009 concerning Wastewater Quality Standards for Bauxite Ore Mining Business and Activities was implemented. This regulation requires the wastewater of Bauxite mining activities to comply with the environmental quality standards and needs to be managed.

Management to control erosion potential could start with simple methods predictions using spatial modeling using Geographic Information System (GIS) applications. GIS could be used to solve spatial problems, such as planning and management (Jaya, 2002). One GIS spatial model that predicts erosion is the Geospatial of Water Erosion Prediction Project (GeoWEPP) model. It is an erosion prediction model based on weather, infiltration theory, soil, plant science, hydrology, and mechanical erosion (Flanagan and Nearing, 1995). GeoWEPP spatial modeling analysis predicts the magnitude of erosion and the location of sedimentation to be used in making a management plan and its cost budget. Therefore, this study aimed to predict the amount of erosion at the location of Bauxite ore mining activities, map the predicted location of sedimentation, and make management plans and costs for erosion control.

METHOD

Location

This study was conducted in Sandai District, Ketapang Regency, West Kalimantan Province. The location was selected purposively in the planned mining area of PT XYZ is divided by catchment area into 30 Blocks (Hill) covering 13 602.48. In addition, this was conducted from August 2020 to February 2021.

Equipment and Materials

This study aimed to predict the amount of erosion using computers and computer software Arc GIS 10.4. The materials used comprised DEM (DEMNAS) images, land cover, LIDAR image 2016, and soil type maps, as well as data on rainfall and temperature.

Data Collection

Data were collected from relevant agencies and PT XYZ. Rainfall, maximum, and minimum temperature data were obtained from BMKG online data for the Rahadi Oesman Meteorological Station, while 2020 land cover data were collected from the Ministry of Environment and Forestry. DEMNAS map was obtained from the Geospatial Information Agency (BIG), and soil type data was obtained from the Center for Research and Development of Agricultural Land Resources (BBSDLP). Additionally, LIDAR image data and 2019 EIA Documents were collected from PT XYZ. Analysis was conducted based on data from the agency, and no field survey was carried out due to limited time and the conditions of the Covid-19 pandemic.

Data Analysis

GeoWEPP Database Development and Analysis Process

GeoWEPP spatial modeling was performed to obtain predictive data on the study site's magnitude of erosion and sedimentation locations. The data analysis process is presented in the flow chart in Figure 1 with the following explanation:

1. Making land-use maps
   Land use maps are made by updating land cover maps to obtain information on spatial land use conditions. Information was obtained from land cover data made by the Ministry of Environment and Forestry. The data were updated with LIDAR image maps, Landsat 8 OLI satellite imagery, and Google Earth application using ArcGIS 10.4 software. Monitoring large areas and slow changes is conducted using medium resolution such as Landsat Satellite Imagery (Prasetyo, 2017).
2. Topographic map making
   The elevation and slope maps were obtained from the results of DEMNAS data processing from the Geospatial Information Agency and processed using ArcGIS 10.4 software. The processing results are catchment area boundaries, elevation, maps, and slopes.
3. Climate data analysis
   Climate data is processed using the Climate Generator (CLIGEN) software available in GeoWEPP to ensure data continuity. The data used consists of Rainfall, maximum, and minimum temperature data were obtained from BMKG online data for the Rahadi Oesman Meteorological Station.

Soil Data Analysis

Soil type data obtained from BBSDLP were analyzed based on physical and chemical properties of the soil from laboratory analysis in EIA Document PT XYZ. Purposive sampling was used in the primary data in the field using the soil type approach to represent the overall condition of the landform in the same characteristics.

Mining Area Plan Simulation

The mining area plan was simulated to determine the location of the mine pit and road. The plan is based on the mining plan of PT XYZ and EIA Document.

Database Development

GeoWEPP model process used topographic, land use, and soil type data in ASCII format. An analysis was conducted by determining the outlet point using continuous climate data.

Spatial Modeling with GeoWEPP

In the analysis in GeoWEPP integrated with ArcGIS 10.4, the data were not calibrated due to limited time and the COVID-19 pandemic conditions. WEPP model has been used successfully in evaluating natural resource problems using real and interrill separation processes in computer simulation programs in extensive project experiments (Flanagan *et al*., 2007). Although the WEPP model has excellent results, it is not calibrated (Laflen *et al*., 2004) with high predictive accuracy (Igwe *et al*., 2017).

Calculating Mine Erosion Magnitude and Mapping Sedimentation Locations

The calculation of the erosion magnitude and the sedimentation location used the output of the GeoWEPP model. The outputs include the amount of runoff and sedimentation and its predictions. This involved using a decision-maker perspective, geospatial environmental assessment approach to efficient decisions. It represents the most complex approach using the most readily available data (Renschler, 2003).

Calculating The Size and Placement of The Settling Pond

The management plan is to be carried out in constructing drainage and settling ponds, which sizes are based on mine erosion and runoff. The settling pond placement is based on a map of the sedimentation location. The size calculation is based on the Decree of the Minister of Energy and Mineral Resources No. 1827K/30/MEM/2018 Attachment II Guidelines for mining technical management. According to the decree, mining water storage and settling facilities should be at least 1.25 times the volume of mine water at the highest rainfall for 84 hours and adjusted to its activities. The size of the settling pond is based on the amount of mine erosion and the amount of surface runoff water in m3 units divided by the depth of the settling pond by 3 meters. Settling pond's placement based on the sedimentation location map. An overview of the Settling pond is presented in Figure 2.

Erosion Management Cost Analysis

This study analyzed land acquisition, water quality testing, and settling pond operational and maintenance costs. Economic analysis is cost analysis. Calculated cost data consists of investment costs of making settling ponds and data on operating costs of settling pond maintenance. The cost data used is obtained from the project leader of the company PT XYZ has been applied in a location adjoining the research site and is still a one-group company.

1. The investment cost of making a settling pond is the cost required to build a settling pond consisting of:
    a. Land acquisition fee, this fee is the cost to buy and sell or borrow on land that will be used to make settling ponds. At the research site, the cost of land acquisition with a buying and selling scheme amounted to Rp 10 000 000/ha and land acquisition costs with a loan scheme of Rp 5 000 000/ha. The cost of land acquisition with a buying and selling scheme is categorized as pessimistic costs, while borrowing schemes are categorized as optimistic costs.
    b. Construction costs of settling pond buildings, the making of settling ponds is done by dredging or hoarding an acreage. The settling pond to be built has three ponds. The excavation cost for Optimist Cost is Rp 45 000/m^3 assuming a maximum of 5 KM of transport location, and for pessimistic costs is Rp 50 850/m^3 assuming the transportation location along the >5 KM.
2. The operating costs of settling pond maintenance are the costs required to maintain the settling pond in order to continue functioning, which consists of dredging and transporting sediment costs as well as the cost of testing water samples. The amount of dredging costs amounted to Rp 50 850/m^3, and the cost of water samples amounted to Rp 1 000 000/sample. Dredging and sampling of samples against settling ponds are carried out once a month during surgery. Dredging activities are not carried out in the last month of operation.

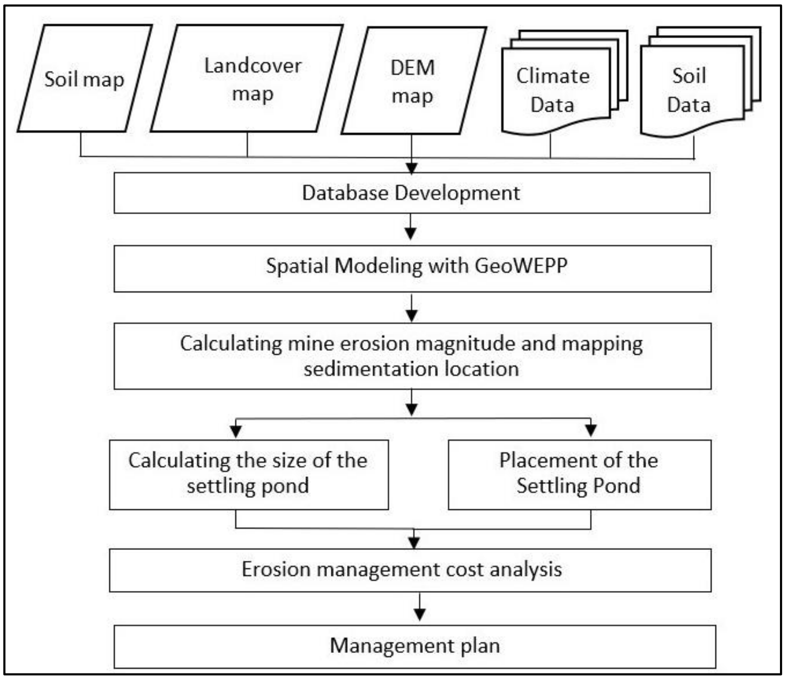
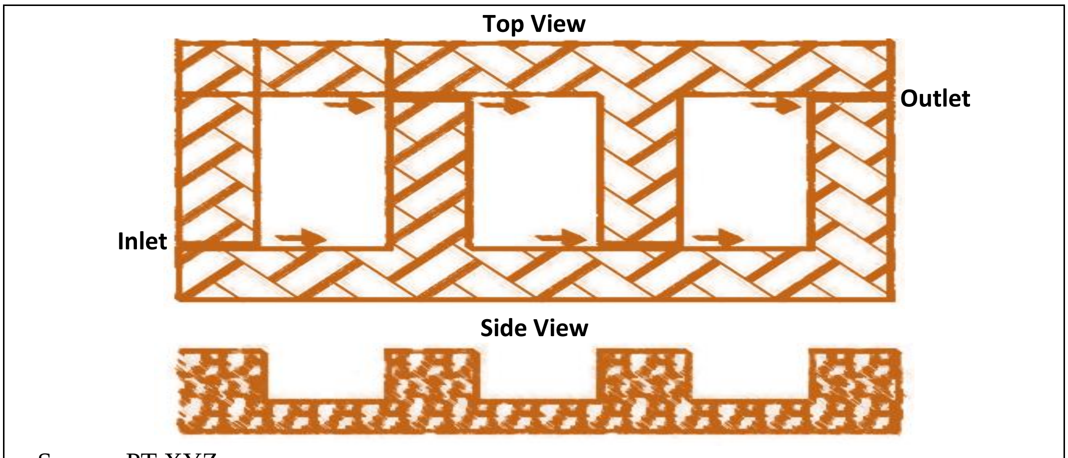


Figure 1 Study flowchart



Source: PT XYZ

Figure 2 Settling pond design

RESULTS AND DISCUSSION

General Condition of Study Site

This study was conducted in Pawan Watershed (DAS) in Sandai Subdistrict and Sungai Laur Subdistrict, Ketapang Regency, West Kalimantan Province. Das Pawan has an elongated shape from north to south with five main rivers, including Pawan, Laur, Kriyau, Kerabai, and Kayung River. This study was conducted in the planned mine opening area of PT XYZ that includes Pawan and Laur Rivers. Bauxite deposits are formed through Laterization in granite, metamorphic and sedimentary rocks (PSDMBP, 2019a). Indonesia's Bauxite potential is 5 234 012 683 tons for resources and 3 609 229 886 tons for reserves (PSDMBP, 2019b). The Laterite in Ketapang has a relatively low Bauxite content of 46.5% and a high silica content of 12% (IAI, 2018). According to Kisman and Pardiarto (2014), Bauxite in Sandai consists of three morphological units, including high hills, low hills, and plains. Stratigraphy occurs from old to young rocks, where the metasedimentary unit consists of sandstone, siltstone and claystone oxidized or lateritized, turning yellow, red, dark red, to limonitic. Figure 3 shows the general condition of the study site.

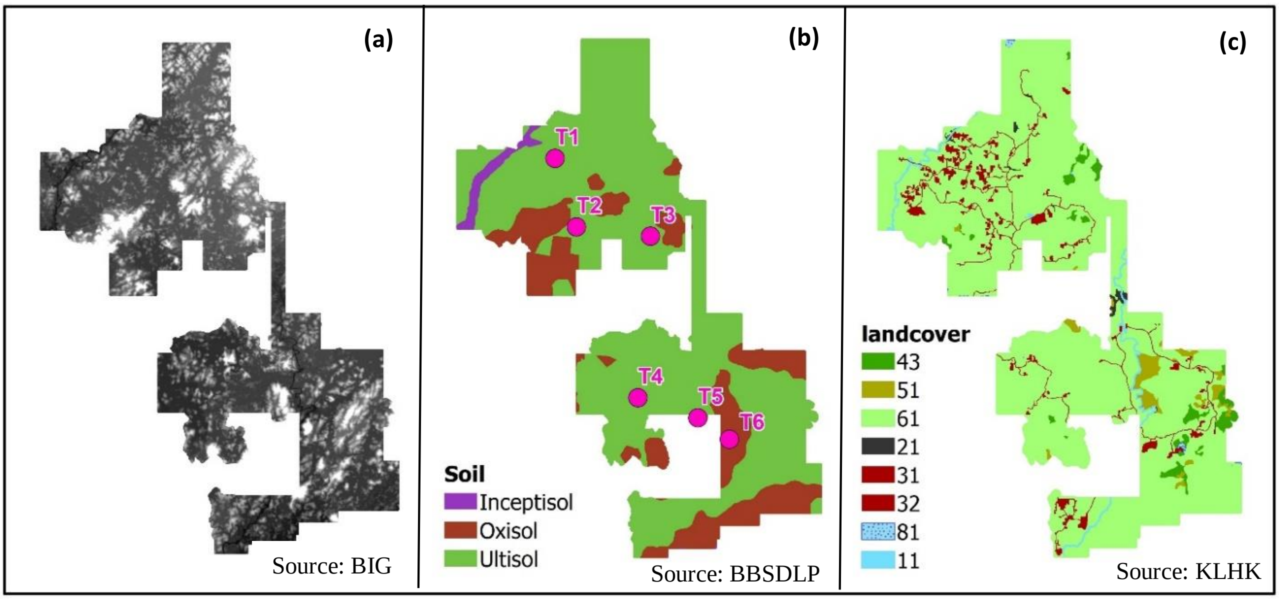


Figure 3 Maps of DEM (a), soil (b), and land cover (c)

Climate

This study analyzed the site's hydrology using climatic data from the class III meteorological station Rahadi Oesman Ketapang. The station is the closest meteorological station that provides complete data. The data were collected on rainfall and maximum and minimum temperature for the 2011-2020 period. The results of CLIGEN analysis of the climate data are presented the climatic conditions of the study area, where the highest rainfall was 408.5 mm/month recorded in December, with 21 rainy days. The highest sun radiation was 459 langley/day in May, the highest maximum temperature was 32.9°C in May, and the lowest maximum temperature was 31.1°C in November. The results of CLIGEN analysis of the climate data are presented in Figure 4 and Figure 5.

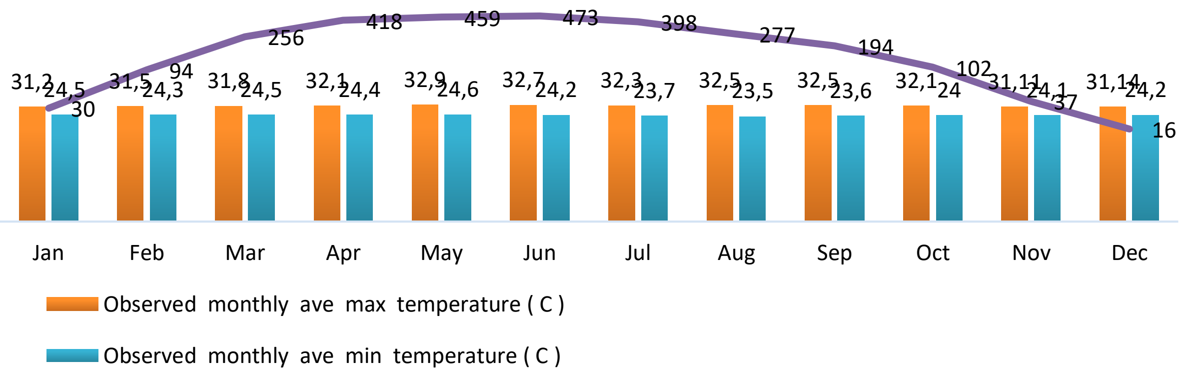


Figure 4 Graphic of temperature and solar radiation (Source: BMKG Station Rahadi Oesman)

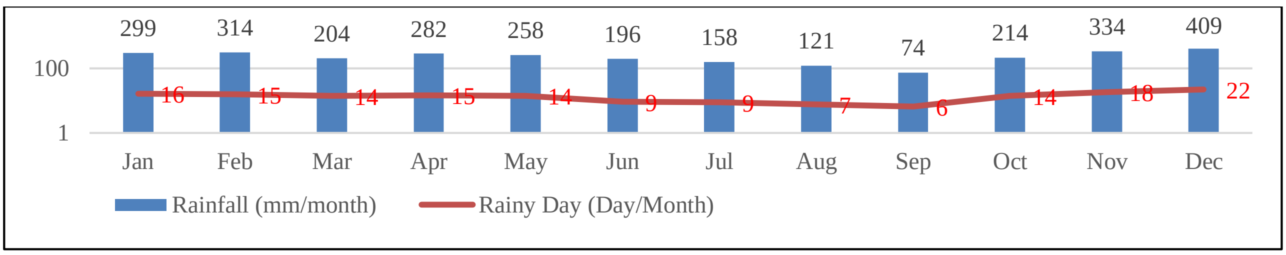


Figure 5 Graphic of rainfall and rainy day (Source: BMKG Station Rahadi Oesman)

Topography

Topographic conditions influence hydrological analysis by causing runoff differences and contributing to erosion and high sediment yields (Igwe *et al*., 2017). The runoff is higher when the slope is longer and sloping (Arsyad, 2010). The study area was 41% flat and 20% slightly steep, as shown in Table 1. The area is 40% flat, though there is a need for Bauxite mining management. Bauxite ore mining activities are generally found in hilly areas and potentially cause large runoff and sediment.

Table 1 Slope Class at the study site

Slope Class (%)	Classification	Area	
		Ha	%
0 - 8	Flat	5 613.41	41
>8 - 15	Ramps	2 136.14	16
>15 - 25	Slightly steep	2 766.05	20
>25 - 40	Steep	2 283.89	17
> 40	Very Steep	802.99	6

Soil

Soil type also affects erosion and runoff because its physical and chemical properties impact its ability to withstand water runoff. Maps from BBSDLP in 2016 showed that the dominant soil order at the study site is Ultisol. The study sites' soil types and physicochemical properties are presented in Table 2.

Table 2 Soil type at the study site

Soil Type	Ordo	Area	
		(ha)	%
Acrudoxic Kandiudults	Ultisol	511.91	4
Acrudoxis Kandiudults	Ultisol	1 384.41	10
Fluventic Dystrudepts	Inceptisol	119.17	1
Typic Hapludox	Oxisol	427.71	3
Typic Kandiudox	Oxisol	1 584.31	12
Typic Kandiudults	Ultisol	123.42	1
Typic Kanhapludults	Ultisol	3 597.77	26
Xanthic Hapludox	Oxisol	5 853.79	43

Data on the soil's physical and chemical characteristics were taken from the Environmental Impact Analysis Document (AMDAL) of PT XYZ through sampling on June 22, 2019. In GEOWEPP analysis, soils were grouped based on order. WEPP was used because it predicts almost all types of land (Laflen and Flanagan, 2013).

Land Use (Land Cover)

Land use affects the amount of erosion and runoff, contributing to high sediment (Igwe *et al*., 2017). Surface runoff is influenced by land use, slope, and soil type (Arsyad, 2010). The study location was 62.40% Dryland Farm Mixed shrubland, followed by plantations at 22.93%, as presented in Table 3. The mining area shown in the land cover map is the planned area of the company PT XYZ. The area had not been cleared during the study and was used for mining activities. Incorporating mining activities such as pits, roads, and product processing areas into the land cover map simulates erosion and sedimentation.

Table 3 Land cover data

Landcover	Code of USGS Classification	Area (ha)	Area %
Secondary Forest	43	542.19	3.99
Shrubland	51	189.21	1.39
Dryland Farm Mixed shrubland	61	8 488.03	62.40
Plantation	61	3 118.51	22.93
Paddy	81	10.96	0.08
Open Water	11	5.26	0.04
Residential	21	42.96	0.32
Mine Road	32	386.37	2.84
Mine Area	31	818.99	6.02

Amount of Erosion of Bauxite Mining Activities

Erosion is the movement of soil or parts of land from one place to another (Arsyad, 2010) by natural media, such as water and wind (Arsyad, 2010; Asdak, 2010). It occurs due to changes in land use and the topographical structure of the watershed (Yüksel *et al*., 2016). Bauxite mining activities change soil chemical properties and cause a loss of 168.8 tons/ha of natural forest biomass (Wasis *et al*., 2018).

The magnitude of erosion and sedimentation in GeoWEPP is simulated in the sub-watersheds or the planned mining area. GeoWEPP model simulates sustainable sediment discharges in sub-watersheds of various sizes, topography, and land use (Amaru and Hotta, 2018). Furthermore, it simulates runoff and sediment yields (Zinziao, 2009) with accurate predictions (Haque *et al*., 2016). The simulated mining block is divided into 30 hills of 13 602 ha, with the mining areas consisting of pit and roads. Moreover, GeoWEPP could assess mines' hydrological and erosional impacts (Wu *et al*., 2011), producing 150 186 m3/month sediment and 4 202 267 m^3/month runoff. The simulation of erosion on the hill is shown in Figure 6.

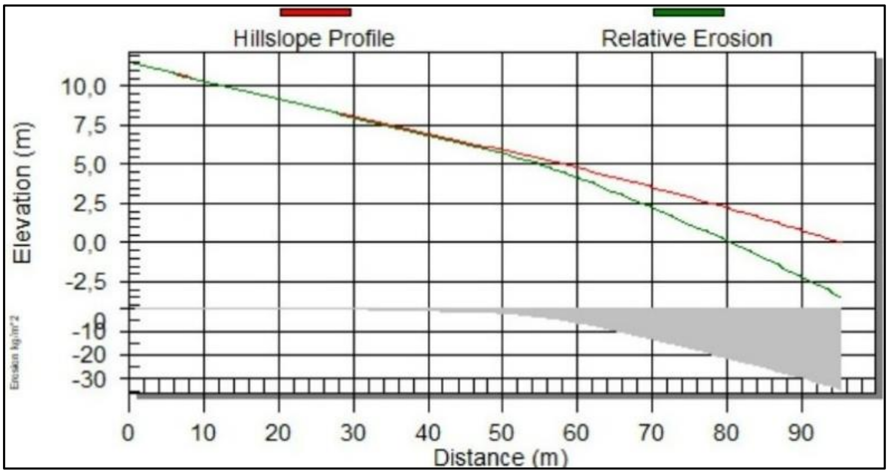


Figure 6 Graph of erosion at the study site

GeoWEPP has limitations, such as its inability to simulate relatively flat areas (Kusmawati, 2006), and produces values lower than the observed values (Demir and Oğuz, 2019). The sediment yields simulated by WEPP are lower than those measured in the field (Pieri *et al*., 2007). The proposed Hill 3 mine area covers 1 974.66 ha, making it the largest, followed by the magnitude of sedimentation. The largest runoff occurred at Hill 3 of 44 344 m^3/month and 603 482 m^3/month. The amount of runoff and sedimentation for each hill is presented in Table 4.

Table 4 Prediction of erosion at bauxite mining sites

No	Block	Block Area (ha)	Mine Area (ha)	Run Off (m^3/bulan)	Sediment (m^3/bulan)
1	Hill 1	68.88	5.40	19 027	660
2	Hill 2	215.96	48.34	63 091	5 904
3	Hill 3	1 974.66	358.87	603 482	44 344
4	Hill 4	1 818.02	88.54	503 867	10 886
5	Hill 5	1 618.75	164.81	534 684	20 233
6	Hill 6	464.42	82.93	173 677	10 647
7	Hill 7	1 865.03	56.38	577 390	7 120
8	Hill 8	436.65	9.35	187 944	1 345
9	Hill 9	374.15	45.45	113 093	5 696
10	Hill 10	132.54	7.29	64 430	1 048
11	Hill 11	63.15	24.61	19 138	3 005
12	Hill 12	1 524.23	51.59	419 989	6 592
13	Hill 13	153.73	7.46	42 068	911
14	Hill 14	17.64	6.55	5 319	799
15	Hill 15	9.92	6.10	3 200	745
16	Hill 16	6.67	3.53	2 101	431
17	Hill 17	12.95	4.31	3 862	526
18	Hill 18	142.23	33.23	61 630	4 648
19	Hill 19	22.21	9.42	8 886	1 300
20	Hill 20	61.63	7.38	17 243	901
21	Hill 21	205.07	10.61	56 175	1 296
22	Hill 22	75.26	18.32	21 859	2 237
23	Hill 23	162.20	18.42	43 258	2 249
24	Hill 24	1 197.93	17.73	384 393	2 165
25	Hill 25	355.24	23.65	93 887	2 887
26	Hill 26	121.71	18.37	34 169	2 243
27	Hill 27	97.10	32.54	28 960	3 973
28	Hill 28	174.99	9.58	50539	1 170
29	Hill 29	118.31	13.21	33 083	1 613
30	Hill 30	111.25	21.38	31 821	2 610
	Total	13 602.48	1 205.36	4 202 267	150 186

Prediction of Bauxite Mining Sedimentation Locations

Prediction of the direction and the magnitude of sedimentation is necessary to determine the location and size of the planned construction of a settling pond. In this situation, data processing using GeoWEPP produced 30 sub-watersheds or channels that help determine the outlet point. WEPP is useful for the time-consuming and inexpensive estimation of soil erosion (Demir *et al.*, 2018) and allows for easier model setup for larger and more complex watershed simulations (Flanagan *et al.*, 2013). The settling pond or outlet point location is presented in Figure 7.

Management Plan

Settling Pond Construction

A settling pond is very important in mining activities to collect water and deposit solid particles from the mining area. The water coming out of the mining site does not cause turbidity and silting of the river due to the solid particles carried along. Therefore, settling ponds are effective as a mine wastewater management method (Wahyudin *et al*., 2018)

In Bauxite mining, treatment at the settling pond does not involve chemicals. The size of the settling pond area to be built is adjusted to the predicted total sediment and runoff. The location and area of the settling pond development plans are presented in Table 5 and Figure 7. The settling pond design plan for Bauxite mining is a square or rectangular adjusted to field conditions. It has a depth of 3 meters and a minimum of 3 ponds consisting of a Sediment zone, where water with mud enters the pond for settling, a Safety pond zone for periodic inspection of water environmental quality standards, Mud zone for settling mud solids.

Table 5 Location and area of the settling pond construction plan

Blok	Run off and Sedimen (m^3/bulan)	Settling Pond Area (ha)	Building Location of Settling Pond	
			BT	LS
Hill 1	19 687	0.66	110° 27' 55.153"	0° 58' 14.064"
Hill 2	68 995	2.30	110° 28' 25.512"	0° 58' 22.360"
Hill 3	647 825	21.59	110° 29' 23.070"	0° 57' 35.244"
Hill 4	514 753	17.16	110° 30' 58.262"	0° 56' 56.847"
Hill 5	554 918	18.50	110° 27' 38.438"	0° 59' 48.590"
Hill 6	184 325	6.14	110° 30' 49.709"	1° 1' 24.850"
Hill 7	584 510	19.48	110° 33' 8.293"	1° 0' 35.063"
Hill 8	189 288	6.31	110° 30' 28.332"	1° 1' 32.232"
Hill 9	118 788	3.96	110° 33' 48.676"	1° 1' 49.609"
Hill 10	65 478	2.18	110° 30' 31.000"	1° 1' 56.335"
Hill 11	22 143	0.74	110° 31' 20.054"	1° 5' 18.984"
Hill 12	426 582	14.22	110° 31' 49.340"	1° 4' 40.177"
Hill 13	42 979	1.43	110° 34' 27.154"	1° 5' 25.645"
Hill 14	6 118	0.20	110° 35' 11.429"	1° 4' 24.825"
Hill 15	3 946	0.13	110° 35' 13.754"	1° 4' 0.538"
Hill 16	2 533	0.08	110° 35' 26.326"	1° 3' 57.115"
Hill 17	4 388	0.15	110° 36' 26.984"	1° 3' 59.559"
Hill 18	66 279	2.21	110° 37' 49.974"	1° 5' 1.877"
Hill 19	10 187	0.34	110° 38' 3.636"	1° 5' 26.352"
Hill 20	18 143	0.60	110° 31' 50.155"	1° 5' 47.670"
Hill 21	57 471	1.92	110° 33' 38.898"	1° 6' 27.234"
Hill 22	24 096	0.80	110° 35' 4.853"	1° 7' 14.282"
Hill 23	45 507	1.52	110° 37' 49.752"	1° 6' 22.651"
Hill 24	386 558	12.89	110° 31' 53.378"	1° 6' 43.414"
Hill 25	96 774	3.23	110° 38' 27.439"	1° 7' 43.204"
Hill 26	36 412	1.21	110° 37' 4.303"	1° 7' 49.349"
Hill 27	32 933	1.10	110° 37' 47.470"	1° 7' 55.408"
Hill 28	51 709	1.72	110° 36' 36.507"	1° 8' 28.625"
Hill 29	34 697	1.16	110° 33' 19.558"	1° 11' 16.537"
Hill 30	34 432	1.15	110° 33' 54.899"	1° 10' 39.737"
Total	4 352 453	145.08		

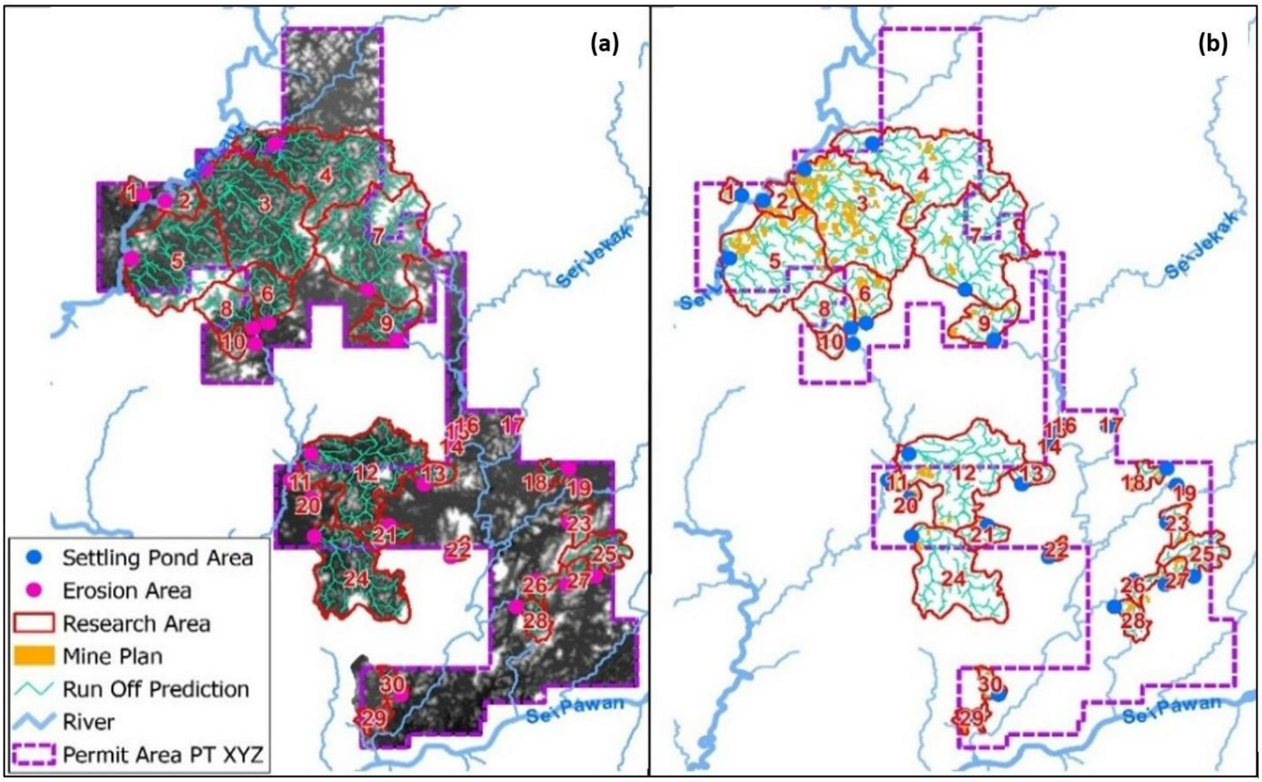


Figure 7 Map of sedimentation location prediction (a) and settling pond location prediction (b)

Investment Cost for Settling Pond

The investment cost for settling pond construction consists of land acquisition and construction costs. Land acquisition cost is the fee of taking over land ownership from the community with a sale and purchase scheme (buy-up) or a borrow-to-use scheme (term). In comparison, the construction cost is the expense of making a settling pond obtained by excavation or stockpiling. The cost of land acquisition with a borrow-to-use and a sale and purchase (buy-up) schemes are Rp 5 000 000/ha and Rp 10 000 000/ha, respectively, while excavation or stockpiling costs Rp 5 850/m^3.

Settling ponds are built on the mining blocks or Hills outlets to accommodate runoff water and sediment from the mining area before being discharged into water bodies. There are 30 settlement ponds to be built, covering 145.08 hectares and a depth of 3 meters. The construction cost for the entire settling pond is Rp 196 585 791 231 for optimistic fees and Rp 222 773 049 768 for pessimistic charges. The cost difference is due to differences in land acquisition schemes, where optimistic costs use buying and selling while pessimistic costs use a borrow-to-use scheme. Meanwhile, the excavation cost for the Optimistic Cost is Rp 45 000/m^3 assuming the transportation location is a maximum of 5 KM and for the pessimistic cost is Rp 50 850/m^3 assuming the transportation location is >5 KM. The details are presented in Table 6.

Table 6 Erosion control investment in Bauxite Ore mining at PT XYZ

Activity Plan	Unit	Volume	Optimistic Costs (Rp)		Pessimistic Costs (Rp)	
			Unit Cost	Total	Unit Cost	Total
Land Acquisition	Ha	145.08	5 000 000	725 408 824	10 000 000	1 450 817 647
Construction	m^3	4 352 453	50 850	195 860 382 407	50 850	221 322 232 120
Total				196 585 791 231		222 773 049 768

Settling Pond Maintenance Operational Costs

The operational costs of settling pond maintenance include dredging and sediment transport and water sample testing costs. Maintenance activities are carried out every month to produce an average of 122 m^3/ha/month sediment. Furthermore, the average operational cost of settling pond dredging in the mine opening area is Rp 37 942 685/month. The average cost of the water sample is Rp 1 000 000/ha, while the total planned cost of settling pond maintenance is Rp 3 139 414 818. The costs in detail are presented in Table 7. The time for mining activities for each mining block (hill) is different. One set of mining equipment consisting of one excavator and 30 dump trucks has a 6 ha/month capacity. The longest mining activity was 33 months, carried out on block hill 3.

Table 7 Planned settlement pond maintenance costs for each block

Block	area of mining activities (ha)	Pit Mine Area (ha)	Mining time (month)	Maintenance		
				Number of Dredging	Dredging Costs (Rp)	Cost of Water Quality Sample (Rp)
Hill 1	5.40	3.00	1	0	-	1 000 000
Hill 2	48.34	27.32	5	4	149 053 017	5 000 000
Hill 3	358.87	206.13	34	33	1 244 097 638	34 000 000
Hill 4	88.54	41.45	7	6	225 066 719	7 000 000
Hill 5	164.81	97.62	16	15	561 849 126	16 000 000
Hill 6	82.93	42.70	7	6	235 029 923	7 000 000
Hill 7	56.38	17.50	3	2	77 059 897	3 000 000
Hill 8	9.35	6.00	1	0	-	1 000 000
Hill 9	45.45	20.76	3	2	76 461 609	3 000 000
Hill 10	7.29	0.57	0	0	-	1 000 000
Hill 11	24.61	15.62	3	2	74 505 633	3 000 000
Hill 12	51.59	19.88	3	2	77 969 517	3 000 000
Hill 13	7.46	2.00	0	0	-	1 000 000
Hill 14	6.55	3.53	1	0	-	1 000 000
Hill 15	6.10	0.62	0	0	-	1 000 000
Hill 16	3.53	0.63	0	0	-	1 000 000
Hill 17	4.31	2.86	0	0	-	1 000 000
Hill 18	33.23	24.00	4	3	128 057 655	4 000 000
Hill 19	9.42	1.46	0	0	-	1 000 000
Hill 20	7.38	4.00	1	0	-	1 000 000
Hill 21	10.61	3.19	1	0	-	1 000 000
Hill 22	18.32	10.50	2	1	37 252 814	2 000 000
Hill 23	18.42	9.00	2	1	37 252 818	2 000 000
Hill 24	17.73	8.50	1	0	-	1 000 000
Hill 25	23.65	6.00	1	0	-	1 000 000
Hill 26	18.37	8.86	1	0	-	1 000 000
Hill 27	32.54	19.91	3	2	74 505 632	3 000 000
Hill 28	9.58	7.00	1	0	-	1 000 000
Hill 29	13.21	6.68	1	0	-	1 000 000
Hill 30	21.38	10.55	2	1	37 252 819	2 000 000
Total	1 205.36	627.84	104	80	3 035 414 817	104 000 000

Postoperative Management

The settling pond would not be dredged to ensure reclamation and revegetation in the last month of mining. Reclamation begins with land management and planting cover crops to reduce erosion and increase soil fertility. Also, overburden should be minimized and dams and drains built to reduce impacts on soil quality (Kamble and Bhosale, 2019b).

GeoWEPP simulation results showed that cover crop planting significantly reduced erosion or sediment. The analysis found that soil tillage and certain plant varieties could be modeled effectively (Demir and Oğuz, 2019). An open ex-mining area produces 80.76 ton/ha/year sediment, which could be reduced to 3.03 ton/ha/year and 0.02 ton/ha/year during the cover crop growth and maturity, respectively. Erosion, sediment, and runoff control techniques prioritize the vegetative method by maintaining ground cover vegetation (Suhartanto, 2005). Therefore, cover crops should be planted immediately after completing the mining activities.

CONCLUSION

The analysis showed a simulation of 30 hills covering 13 602.48 ha, producing sediment of 150 186 m^3/month and the runoff of 4 202 267 m^3/month. GeoWEPP analysis on the planned mining block area obtained 30 outlet points to be used for the settling pond construction. Moreover, the optimistic and pessimistic costs of constructing the entire settling pond are Rp 222 047 640 944 and Rp 222 773 049 768, respectively. The settling pond maintenance cost at all outlet points during operation is Rp 3 139 414 818. Planting cover crops in ex-mining areas effectively reduce erosion 0.02 ton/ha/year during the cover crop growth and maturity, respectively.

ACKNOWLEDGMENT

The authors express gratitude to the Ministry of Environment and Forestry, the Center for Research and Development of Agricultural Land Resources, the Geospatial Information Agency, and the BMKG, particularly the Rahadi Oesman Meteorological Station in Ketapang, for becoming a study location and preparing data.

REFERENCES

[ESDM] Kementerian Energi Sumberdaya Mineral Republik Indonesia. 2018. Keputusan Menteri Energi Sumberdaya Mineral Republik Indonesia Nomor 1827K/30/MEM/2018 tentang Pedoman Pelaksanaan Kaidah Teknik Pertambangan yang Baik. Jakarta (ID): ESDM.

[IAI] International Aluminium Institute. 2018. *Panduan Penambangan Bauksit Berkelanjutan* [Internet]. Australia (AU): World Aluminium. [downloaded 2020 Apr 28]. Available at: http://www.world-aluminium.org/media/filer_public/2019/04/02/sbmg_bahasa_indonesia_final_01-04-2019.pdf.

[PSDMBP] Pusat Sumber Daya Mineral, Batubara dan Panas Bumi. 2019a. *Potensi Logam Tanah Jarang di Indonesia*. Bandung (ID): PSDMBP.

[PSDMBP] Pusat Sumber Daya Mineral, Batubara dan Panas Bumi. 2019b. *Executive Summary Pemutakhiran Data dan Neraca Sumber Daya Mineral dan Batubara Status 2019*. Bandung (ID): PSDMBP.

[Pusdatin ESDM] Pusat Data dan Teknologi Informasi Kementerian Energi dan Sumberdaya Mineral Energi dan Sumberdaya Mineral. 2016. *Dampak Hilirisasi Bauksit Terhadap Perekonomian Regional Provinsi Kalimantan Barat*. Jakarta (ID): Pusat Data dan Teknologi Informasi Kementerian Energi dan Sumberdaya Mineral Energi dan Sumberdaya Mineral.

Amaru K, Hotta N. 2018. Application of GeoWEPP for evaluating sediment yield in a mountain area: Agatsuma Watershed, Japan. *International Journal of Erosion Control Engineering*. 11(1): 1-14.

Anwar M, Pawitan H, Murtilaksono K, Jaya INS. 2011. Respons Hidrologi Akibat Deforestasi di DAS Barito Hulu, Kalimantan Tengah. *JMHT*. 17(3): 119-126.

Arsyad S. 2010. *Konservasi Tanah dan Air*. 2nd ed. Bogor (ID): IPB Press.

Asdak C. 2010. *Hidrologi dan Pengelolaan Daerah Aliran Sungai*. 5th ed. Yogyakarta (ID): Gajah Mada University Press.

Defersha MB, Melesse AM, McClain ME. 2012. Watershed scale application of WEPP and EROSION 3D models for assessment of potential sediment source areal and runoff flux in the Mara River Basin, Kenya. *Catena*. 95: 63-72.

Demir S, Oğuz I. 2019. Determination surface flow and soil loss with wepp hillslope model in Northern Turkey. *Carpathian Journal of Earth and Environmental Sciences*. 14(2): 463-472.

Demir S, Oğuz İ, Özer E. 2018. Estimation of soil losses in a slope area of Tokat Province through USLE and WEPP Model. *Turkish Journal of Agriculture-Food Science and Technology*. 6(12): 1838-1843.

Flanagan DC, Gilley JE, Franti TG. 2007. Water erosion prediction project (WEPP): Development history, model capabilities, and future enhancements. *American Society of Agricultural and Biological Engineers (ASABE)*. 50(5): 1603-1612.

Flanagan DC, Frankenberger JR, Cochrane TA, Renschler CS, Elliot WJ. 2013. Geospatial Application of The water erosion prediction project (WEPP) model. *American Society of Agricultural and Biological Engineers (ASABE)*. 56(2): 591-601.

Flanagan DC, Nearing MA. 1995. *USDA-Water Erosion Prediction Project, NSERL Report No. 10*.Indiana (US): USDA-ARS National Soil Erosion Research Laboratory.

Haque MZ, Rahim SA, Abdullah MP, Embi AF, Elfithri R. Lihan T, Mokhtar M. 2016. Predicting sediment load and runoff in Geo WEPP environment from Langat Sub Basin, Malaysia. *Nature Environment and Pollution Technology*. 15(3): 1077-1082.

Igwe PU, Onuigbo AA, Chinedu OC, Ezeaku II, Muoneke MM. 2017. Soil erosion: A review of models and applications. *International Journal of Advanced Engineering Research and Science (IJAERS)*. 4(12): 138-150.

Jaya INS. 2002. *Aplikasi Sistem Informasi Geografis untuk Kehutanan: Penuntun Praktis Menggunakan Arc/info dan ArcView*. Bogor (ID): Fakultas Kehutanan Institut Pertanian Bogor.

Kamble PH, Bhosale SM. 2019a. Environmental impanct of bauxite mining: A review. *International Journal for Research in Applied Science and Engineering Technology (IJRASET)*. 7: 86-90.

Kamble PH, Bhosale SM. 2019b. Assessment of impact of bauxite mining on environment. *I-manager's Journal on Future Engineering and Technology*. 14(4): 14-21.

Kisman, Pardiarto P. 2014. Karakteristik geokimia unsur tanah jarang dalam endapan bauksit di daerah sandai, Kabupaten Ketapang, Provinsi Kalimantan Barat. *Buletin Sumber Daya Geologi*. 9(3): 161-172.

Kusmawati I. 2006. Pendugaan erosi dan sedimentasi dengan menggunakan Model GeoWEPP (studi kasus Das Limboto. Propinsi Gorontalo) [thesis]. Bandunt (ID): Institut Teknologi Bandung.

Laflen JM, Flanagan DC. 2013. The development of US soil erosion prediction and modeling. *International Soil and Water Conservation Research*. 1(2): 1-11.

Laflen JM, Flanagan DC, Engel BA. 2004. Soil erosion and sediment yield prediction accuracy using wepp. *The Journal of the American Water Resources Association (JAWRA)*. 40(2): 289-297.

Maalim FK, Melesse AM, Belmont P, Gran KB. 2013. Modeling the impact of land use changes on runoff and sediment yield in the Le Sueur watershed, Minnesota using GeoWEPP. *Catena*. 107: 35-45.

Pieri L, Bittelli M, Wu JQ, Dun S, Flanagan DC, Pisa PR, Ventura F, Salvatorelli F. 2007. Using the water erosion prediction project (WEPP) model to simulate field-observed runoffand erosion in the Apennines Mountain Range, Italy. *Journal of Hidrology*. 336: 84-97.

Prasetyo LB. 2017. *Pendekatan Ekologi Lanskap untuk Konservasi Biodiversitas*. Bogor (ID): Institut Pertanian Bogor.

Renschler CS. 2003. Designing geo-spatial interfaces to scale process models: the GeoWEPP approach. *Hydrological Processes*. 17: 1005-1017.

Suhartanto. 2005. Pendugaan erosi, sedimen dan limpasan berbasis model hidrologi WEPP dan SIG di Sub-DAS Ciriung, DAS Cidanau [thesis]. Bogor (ID): Institut Pertanian Bogor.

Suherman DW, Suryaningtyas DT, Mulatsih S. 2015. Dampak penambangan pasir terhadap kondisi lahan dan air di Kecamatan Sukaratu, Kabupaten Tasikmalaya. *Jurnal Pengelolaan Sumberadaya Alam dan Lingkungan (Journal of Natural Resources and Enviromental Management)*. 5(2): 99-105.

Wahyudin I, Widodo S, Nurwaskito A. 2018. Analisis penanganan air asam tambang batubara. *Jurnal Geomine*. 6(2): 85-89.

Wasis B, Arifin, Winata B. 2018. Impact of bauxite mine to natural forest biomass and soil properties in Kas Island, Riau Island Province in Indonesia. *Agriculture and Environmental Science.* 3(3): 264-269.

Wu JQ, Dun S, Rhee H, Liu X, Elliot WJ, Golnar T, Frankenberger JR, Flanagan DC, Conrad PW, McNearny RL. 2011. Applying wepp technologies to western alkaline surface coal mines. In: In: Flanagan DC, Ascough II JC, Nieber JL. *Proceedings of the International Symposium on Erosion and Landscape Evolution (ISELE). The International Symposium on Erosion and Landscape Evolution;* 2011 Sep 18-21; Alaska, Amerika Serikat. Alaska (US): American Society of Agricultural and Biological Engineers (ASABE).

Yüksel EE, Özalp M, Yildirimer S. 2016. Using a Geospatial Interface (Geowepp) to predict soil loss, runoff and sediment yield of kokolet creek watershed. *International Journal of Ecosystems and Ecology Sciences (IJEES)*. 6 (3): 437-442.

Zinziao Y, Xiaoming Z, Lili N. 2009. Simulated multi-scale watershed runoff and sediment production based on GeoWEPP model. *International Journal of Sediment Research*. 24(4): 465-478.