Managing Bank Soil on Surface Mining Operation with USLE Method

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Managing Bank Soil on Surface Mining Operation with USLE Method

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Abstract— **Top soil is a valuable layer in mining activity, hence adequate management is required to maintain the quality, quantity, and mechanical properties. The soil will be used for revegetation to support success in post mining. It will be placed in one area and taken when revegetation area is ready. Soil is loose and has low mechanical properties that make it prone to erosion when it rains. This research was conducted to manage top soil so that the quality can be maintained as well as erosion and sediment loads can be reduced. The analysis used Universal Soil Loss Equation (USLE) method by changing the variable C (cover factor) through *Cymbopogon nardus* planting option. This plant has long roots which increase soil cohesion, is fast growing, and has economic value. The leaves and stems can be distilled to produce essential oils. Planting *Cymbopogon nardus* with a spacing configuration of 0.8 m can reduce erosion by 175.67%, which is smaller than the bare-soil condition. The reduction in monthly erosion was 14.72-49.78 ton/ha/month with an average reduction of 30.14 ton/ha/month or 361.69 ton/ha/year.**

Keywords— **erosion; sedimentation; USLE; cover factor.**

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I. INTRODUCTION

Erosion is a process which occurs on surface that causes movement of soil, rock, and dissolved material from their original place to another [1] (Encyclopædia Britannica 2020). Erosion rate is naturally controlled by climate (precipitation), weathering (material characteristics), geomorphology (topography and drainage system) [2], and land cover vegetation [3], [4]

In a tropical climate zone, rain is one of the main factors for water erosion on soils [5]. Erosion represents soil vulnerability associated with its characteristics, such as biological, chemical, physical, mineralogy, and hydrology [6]. Accelerated erosion could occur if the driving factors for increased erosion such as high rainfall currents, steeper slopes, low vegetation cover are not been anticipated by appropriate countermeasures [7]. Identification of the erosion potential is required in soil conservation practice. Estimation of the rate of soil erosion is necessary for soil loss prediction and determining the suitability of erosion mitigation [8].

Rate of erosion is naturally controlled by physical factors which cover climate (precipitation) [9], weathering (material characteristics), geomorphology (topography and flow patterns). Changes in land use affect the components of the hydrological cycle, resulting in changes in the intensity of runoff and erosion in a watershed [10]. Often times, the potential for erosion is exacerbated by anthropogenic actions on the soil surface which create conditions that are more susceptible to erosion [11].

Erosion is a serious threat to the environment. The erosion of the soil layer causes a decrease in the level of fertility and land productivity [12]–[14]. In addition, erosion can cause deterioration of water quality due to leaching and suspended material; sedimentation of the material; mud flow and soil movement [15]. As a result, erosion could have strong implications for a region's economy [16], especially developing countries and agricultural countries that depend on soil and water resources.

The availability of rainwater causes high weathering and material transportation in greater quantity [4]. Weak resistance of material to weathering and surface condition such as steeper slope also accelerate erosion [2]. While the surface shape or topography of the flow plane also has an impact on the intensity of erosion [17]; anthropogenic factors, especially agriculture could greatly affect soil conditions. [14]. The existence of vegetation and land management can reduce the intensity and susceptibility to erosion [18]. Overall, changes in precipitation (rain), vegetation, and land use factors that are more dynamic in nature have more significance in causing erosion compared to the relatively static characteristics of the material and topography [19].

In general, changes in precipitation (rain) and vegetation are dynamic in nature to drive erosion rate, compared to material characteristics and topography which are relatively stable [20]. Precipitation of rain determines the severity and rate of runoff and erosion. Variation of rain precipitation determines the water content in soil, thus influencing the dynamics of vegetation development and succession with various land uses. Ultimately, it has an impact on the ability of vegetation to inhibit deep erosion [3].

At the end of 2020, it will occur again and is predicted to occur until the end of the first quarter of 2021[21]. This can be a concern because there is an increased risk of erosion due to the potential for an increase in extreme rainfall (precipitation) in 2021-2022. *Cymbopogon nardus* or commonly known as citronella grass is proposed as good cover crop to overcome landslides (erosion) [22]. *Cymbopogon nardus* is perennial tropical plant which belongs to true grass family and always grows throughout the year, so it is suitable for anticipating rain in a full year. The use of *Cymbopogon nardus* is even recommended by Food and Agriculture Organization (FAO) to prevent erosion [23].

Apart from being a barrier to erosion, *Cymbopogon nardus* has prominent economic potential compared to other types of true grass. *Cymbopogon nardus* leaves are a good source of cellulose for making paper and cardboard. Production result of *Cymbopogon nardus* can be consumed as herbal tea drinks and spices for cooking; as well as processed into aromatic oil insect repellent [24].

II. CONCEPT

A. *Universal Soil Loss Equation (USLE)*

Wischmeier and Smith (1978) have developed an empirical model to predict erosion on land known as the Universal Soil Loss Equation (USLE) [25] [26]. Currently this model is used as a practical guide for engineers and still being developed in various countries. The USLE model is expressed as Equation 1.

$$E = R \times K \times LS \times C \times P \qquad (1)$$

In the model, erosion (E) is seen as multiplication of the factor R (erosivity of rainfall (precipitation)) and the factor of environmental resistance, which consists of K (soil erodibility), LS (topographic factor), C (plant cover and agricultural technique), and P (erosion control practice). If one of the factors tends to be zero, the erosion value will also tend to be zero because the model is a multiplication of factors.

Erosivity of rainfall (precipitation) (R) can be determined by Equation 2, which is the equation of Lenvain. In the equation, the erosivity of rainfall (precipitation) is an exponential function of monthly precipitation (p) in centimeters.

$$R = 2.21\, p^{1.36} \qquad (2)$$

B. *2.2. Rainfall*

Data of rainfall (precipitation) used was obtained from precipitation measurement from 2007-2020. At the time of this paper written (October 2020), data for November and December 2020 were not yet available. Tabulation of the data summary is shown in Table 1. Plotting of average monthly precipitation and year of the maximum precipitation occurrence is presented in Figure 1.

On average, the highest precipitation occurred in April to May, while the lowest precipitation occurred in August to October. The other months are transition months. The least difference between maximum and average monthly precipitation was 155.5 mm in January, and the biggest was 519.31 mm in September, which is a dry month. The highest monthly precipitation occurred in 2010 between March and July with an exception of April which was lower than the others.

On an annual basis, 2010 was the year with the highest precipitation, coinciding with one of the largest La Niña events ever recorded then followed by fluctuation of annual precipitation with a return period of 3-4 years (Figure 2). The end of 2020 will coincide with La Niña which is predicted to occur until the end of the first quarter of 2021 as predicted by the Indonesian Meteorology Climatology and Geophysical Bureau [21]. The last three La Niña events in 1988, 1998, and 2010 had a return period of 10 - 12 years. This does not rule out the possibility that high precipitation anomaly may occur at the end of 2020 to 2021 or even 2022, although it may not be as extreme as in 2010.

TABLE I

MONTHLY PRECIPITATION AND RAINFALL INTENSITY OF YEAR 2007 – 2020.

Month	Monthly precipitation (mm)		Year of the maximum precipitation occurrence
	Average	Max.	
January	181.50	337.00	2020
February	253.39	516.83	2016
March	282.13	717.50	2010
April	327.26	520.00	2011
May	338.93	741.00	2010
June	272.37	718.80	2010
July	269.23	731.25	2010
August	145.63	511.00	2010
September	144.19	663.50	2010
October	138.37	595.00	2010
November	195.51	366.40	2013
December	221.15	695.50	2009

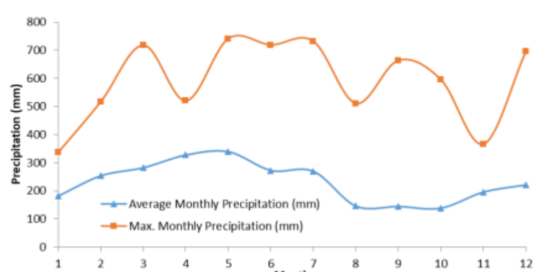

Fig. 1 Monthly precipitation plot showing average and maximum precipitation occurrence caused

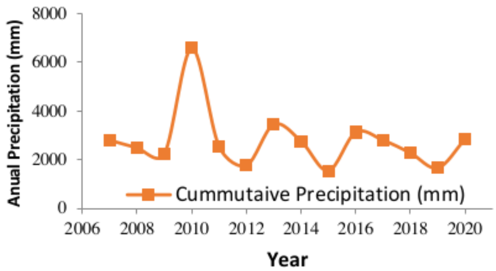

Fig. 2 Annual precipitation of the 2007 – 2020 period, showing precipitation anomaly.

C. Soil Material

Soil material that is commonly found in the research area is latosol which is tropical soil, also known as oxisol or ferralsol. The characteristic of this material is a high composition (at least 40%) of clay that has a reddish yellow brown color due to the high content of iron oxide. The erodibility factor (K) of latosol material ranges from 0.09 to 0.27, with moderate weighted criteria of 0.22 to 0.31. Materials at the research area is consist of clay and quartz sand with low mechanical properties [27]–[29]. The sandy materials consisting of quartz minerals with grain size of sand (0.06-2 mm) have a friction angle of 35 degrees [30]. The permeability of granite weathered soil <10^{-7c}m/s [31].

D. Topographic Factor

Slope length (L) is measured from a location on soil surface where erosion begins to occur to a location where deposition occurs. In practice, the value of L is often calculated at the same time with steepness factor (S) as slope factor (LS). Slope factor classification is shown in Table 2. The topography in research area has a wavy topography with slope ranging between 8-15%. In this condition, it is included in Class II with a slope factor (LS) of 1.4.

TABLE III
SLOPE FACTOR CLASSIFICATION. REPRODUCED AFTER

Class	Slope gradient (%)	Topographic factor (LS)
I	0 – 8	0.4
II	8 – 15	1.4
III	15 – 25	3.1
IV	25 – 40	6.8
V	> 40	9.5

E. Plant Cover and Preventive Measure

Cymbopogon nardus is the optimum plant for grass barrier (Food and Agriculture Organization 2012) because it meets the following criteria:

- Grove of plant is stiff and lush
- Extensive root system
- Able to withstand stress with rapid secondary growth
- Does not proliferate like weeds, and is effective in narrow width
- Narrow leaves which prevent insects from breeding

Many researchers mentioned the vegetation factor (C) values, but did not explain the configuration of *Cymbopogon nardus* planting pattern in the C factor value [13], [23]. Study on clump spacing of *Cymbopogon nardus* on erosion rate has been carried out with spacing of 1 m, 0.8 m, and 0.6 m [33], presented in Figure 3. The fixed variables are R (erosivity of rainfall (precipitation)), K (soil erodibility), LS (topographic factor), and P (erosion control practice). Thus, the value of C factor can be determined from ratio of the erosion weight at a certain spacing to the control.

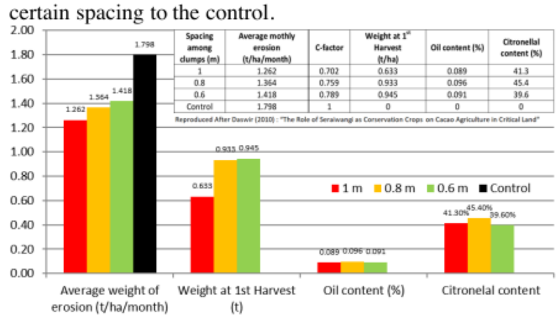

Fig. 3 Graphical representation on effect of clump spacing toward erosion, productivity, and crop quality for various clump spacing.

Based on this study, information was obtained that planting of *Cymbopogon nardus* (citronella grass) showed a positive effect on soil conservation. The lowest erosion weight was at 1 m spacing, while the best productivity and crop quality of *Cymbopogon nardus* was obtained with a spacing of 0.8m. The 0.8m spacing showed the most optimum condition in terms of erosion prevention, productivity, and crop quality, compared to the control (without planting *Cymbopogon nardus*).

Each planting point should be planted at an angle of 45°, parallel to the slope, following the topography in a staggered pattern. The planting process needs to ensure the effective root growth first and then enhances the soil conservation function. To maximize conservation impact, each plot of grass barrier should be at least 30-40 feet (9.12-12.1 m) wide from the top to the bottom of the plot, and spread along the exposed slope surface [23]. Criteria for management and plantation factors along the contour line is shown in Table 3.

TABLE III
P FACTOR FOR SLOPE GRADIENT ON SOIL MANAGEMENT AND PLANTATION ALONG THE CONTOUR LINE. REPRODUCED AFTER

Slope gradient	P factor
0 – 8%	0.5
9 – 20%	0.75
>20%	0.9

III. RESULT AND DISCUSSION

Based on data of monthly rainfall (precipitation) in 2007-2020, erosivity of rainfall factor (R) was calculated by Lenvain equation (Equation 2) from the monthly rainfall (precipitation) and then plotted by month. Figure 4 shows the monthly R factor obtained from the average rainfall (precipitation) each month from 2007 to 2020. The anomaly of increase in rainfall (precipitation) that occurred in 2010 due to La Niña as well as the maximum rainfall (precipitation) that occurred in the 2007-2020 period were used as potential value of maximum rainfall and calculated to obtain potential value of maximum rainfall erosivity factor. This is meant to be a consideration and a reminder in planning design and scheduling maintenance due to the similar potential of anomaly in 2020-2021 which is marked by La Niña that will begin to occur in November 2020.

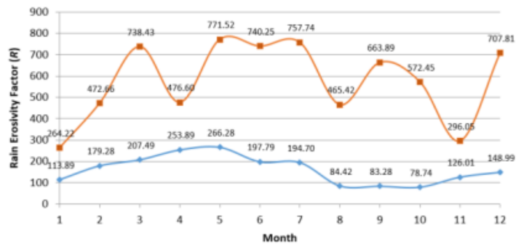

Fig. 4 Monthly rainfall erosivity and potential maximum monthly rainfall erosivity.

The average and maximum rainfall erosivity (Rm and Rmx) were calculated for each month and presented in Figure 4. The annual erosivity Ra = 1,934.76 is the accumulation of the monthly erosivity Rm (January – December); while the potential value of maximum annual rainfall erosivity Ramx = 6,927.04 is the accumulation of the maximum monthly erosivity Rmx (January – December).

The soil erodibility factor (K) of latosol material was determined to be 0.31. The topographic factor (LS) was 1.4 for wavy topography with slopes ranging between 8-15% (Class II)

The vegetation used as a cover crop was *Cymbopogon nardus*, which is recommended by FAO as a plant to prevent erosion [23]. Planting was carried out with a clump spacing of 0.8 m to optimize erosion prevention, productivity, and crop quality. The plant cover and agricultural technique factor (C) at 0.8 m spacing is 0.759.

Erosion control practice was carried out by planting according to the contour pattern, as recommended by FAO. The erosion control factor (P) in this practice for the topography of research area (slope 8-15%) was 0.75. Summary for the values of the factors used in calculating the amount of erosion is presented in Table 4.

TABLE IV
SUMMARY OF EROSION DETERMINING FACTOR (USLE) FOR EROSION CALCULATION.

Factors	Value	Remarks
Ra	1,934.76[a]	
Ramx	6,927.04[b]	
K	0.31*; **	Latosol
LS	1.4*; **	Class II; slope gradient 8-15%
C	0.759* 1**	*0.8 m spacing
P	0.75* 1**	*Soil management and plantation along contour according to FAO

[a]used for calculation of average annual erosion; [b]used for calculation of maximum annual erosion; *used for soil with grass barrier (Cymbopogon nardus); **used for bare-soil.

Erosion that occurred within a certain period of time was calculated using USLE model (Equation 1). The calculation was carried out to determine monthly erosion rate (Figure 5) and annual erosion rate (Figure 6). The pattern of erosion that occurs every month follows the pattern of monthly rainfall (precipitation); this is in accordance with the statement that erosion is largely determined by erosivity due to rain [2], [4], [31].

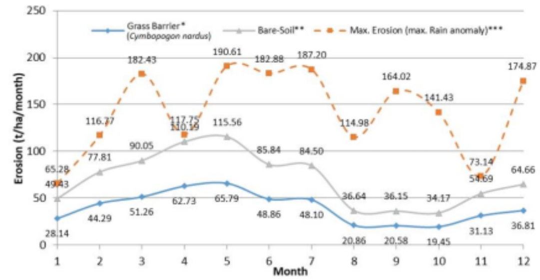

Fig. 5 Erosion for each month of the year.

Figure 5 shows the monthly erosion rate calculated from the average monthly rainfall from 2007 to 2020 (thick line) in soil condition planted by Cymbopogon nardus as grass barrier and in bare-soil condition. There is a decrease in the monthly erosion value due to Cymbopogon nardus planting of 14.72 ton/ha/month with an average decrease in erosion of 30.14 ton/ha/month. The dashed line shows the maximum erosion potential calculated based on the highest rainfall ever recorded, mainly as a result of the La Niña event in 2010.

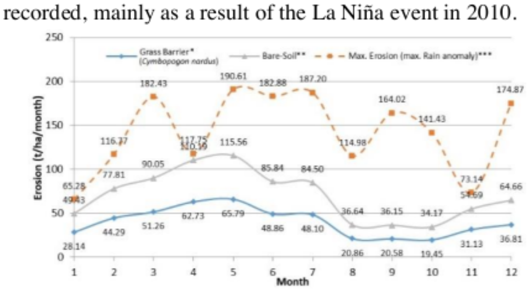

Fig. 6 Summary of annual erosion in the research area.

Based on the calculation result, planting Cymbopogon nardus as grass barrier reduced erosion by 361.69 ton/ha/year. It reduced erosion up to 175.67% compared to bare-soil condition or without the grass barrier. However, it is important to note that the La Niña phenomenon that occurred in 1988, 1998, and 2010 has a return period of 10-12 years. Thus, increased rainfall in 2020-2021 needs to be watched out.

If the maximum rainfall is achieved, there will be an erosion difference of 37.14-143.44 ton/ha/month with an average of 102.78 ton/ha/month or 358.03% in soil condition that has been planted. This needs to be watched out, especially in critical lands. Moreover, indirectly, erosion due to increased rainfall will have an impact on the accumulation of sedimentation towards sediment pond. This of course requires maintenance and operational cost that need to be taken into account.

IV. CONCLUSION

Planting Cymbopogon nardus with a spacing configuration of 0.8 m can reduce erosion by 175.67%, which is smaller than the bare-soil condition. The reduction in monthly erosion was 14.72-49.78 ton/ha/month with an average reduction of 30.14 ton/ha/month or 361.69 ton/ha/year. The recommended cropping pattern is staggered, following the contour pattern according to FAO recommendation. With a spacing of 0.8 m, the production of Cymbopogon nardus is expected to reach 0.993 ton/ha.

As a precaution, design planning and countermeasures need to be reviewed not only annually, but also monthly. Vigilance needs to be increased accompanied by good preparation and planning. Figure 5 can be used as a guideline in planning and determining policies related to the potential of increased rainfall anomaly against the monthly potential of erosion due to La Niña that will begin to occur at the end of 2020, of which the impact can last for at least the next 1-2 years.

Direct testing (pilot test) of planting effectiveness and productivity is required considering the conditions at each location can be different from the references. By doing so, more accurate data can be obtained regarding the productivity and effectiveness of Cymbopogon nardus planting to overcome erosion in a specific location

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