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# Managing Bank Soil on Surface Mining Operation with USLE Method

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*Abstract*— **The most valuable layer in mining activities is topsoil, so adequate management is needed, especially in maintaining its quality, quantity, and mechanical properties. The land is used for revegetation, which supports post-mining success and can return the land to its original condition. This process starts by placing the soil in one area, and when the revegetation area is ready, it is removed. Soil is loose and has low mechanical properties, so it is susceptible to erosion when it rains. The research objective is to manage topsoil to maintain quantity and quality, and erosion and sediment load can be reduced. The analysis was carried out using the Universal Soil Loss Equation (USLE) method by changing the variable C (cover factor) through the option of planting *Cymbopogon nardus*. This plant has long roots that can increase soil cohesion, grows fast, and has economic value. Planting *Cymbopogon nardus* with a spacing of 0.8 m can reduce erosion by 175.67%, less than the bare soil condition. The value of the C factor decreased from 1 to 0.759 after planting *Cymbopogon nardus* with that spacing. The decrease in monthly erosion is 14.72-49.78 tons/ha/month, with an average decrease of 30.14 tons/ha/month or 361.69 tons/ha/year. Planting *Cymbopogon nardus* effectively reduces erosion at a lower cost and effort. This plant provides many benefits after leaves and stems can be distilled to produce essential oils.**

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

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## I. INTRODUCTION

Erosion is a process that occurs on the surface that causes the movement of soil, rock, and dissolved material from their original place to another [1], [2]. The erosion rate is naturally controlled by climate (precipitation), weathering (material characteristics), geomorphology (topography and drainage system) [3], and land cover vegetation [4], [5].

In a tropical climate zone, rain is one of the main factors for soil water erosion [6]. Erosion represents soil vulnerability associated with its characteristics, such as biological, chemical, physical, mineralogy, and hydrology [7]. Therefore, several factors can trigger accelerated erosion, such as high rainfall flows, steeper slopes, and low vegetation cover, which are not anticipated with proper precautions [8]. So, the identification of erosion potential is needed in soil conservation practices. One thing that must be identified is the estimation of soil erosion rate, it needs to be done, so it can know the prediction of soil loss and determine the suitability of erosion mitigation [9].

The rate of erosion is naturally controlled by physical factors, which include climate (rainfall) [10], weathering (material characteristics), and geomorphology (topography and flow patterns). Changes in land use affect the hydrological cycle components, resulting in changes in the intensity of runoff and erosion in a watershed [11]. The potential for erosion is often exacerbated by anthropogenic actions on the soil surface, which create conditions that are more susceptible to erosion [12].

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 [13]–[15]. In addition, erosion can cause deterioration of water quality due to leaching and suspended material, sedimentation of the material, mudflow, and soil movement [16]. As a result, erosion could have strong implications for a region's economy [17], especially in 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 [5]. Weak material resistance to weathering and surface conditions such as the steeper slope also accelerate erosion [3]. While the surface shape or topography of the flow plane also impacts the intensity of erosion [18], anthropogenic factors, especially agriculture, could greatly affect soil condition [15]. The existence of vegetation and land management can reduce the intensity and susceptibility to erosion [19]. Overall, changes in precipitation (rain), vegetation, and land-use factors more dynamic in nature have more significance in causing erosion than the material's relatively static characteristics and topography [20].

In general, changes in precipitation (rain) and vegetation are dynamic to drive erosion rate, compared to material characteristics and topography, which are relatively stable [21]. Precipitation of rain determines the severity and rate of runoff and erosion. Variation of rain precipitation determines the water content in the soil, thus influencing the dynamics of vegetation development and succession with various land uses. Ultimately, it impacts the ability of vegetation to inhibit deep erosion [4].

It occurs again at the end of 2020 and is predicted to occur until the end of the first quarter of 2021 [22]. 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*, commonly known as citronella grass, is proposed as a good cover crop to overcome landslides (erosion) [23]. *Cymbopogon nardus* is a perennial tropical plant that belongs to the true grass family and always grows throughout the year, so it is suitable for anticipating rain in a full year. Cymbopogon nardus is recommended by Food and Agriculture Organization (FAO) to prevent erosion [24]. 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. The production result of *Cymbopogon nardus* can be consumed as herbal tea drinks and spices for cooking and processed into aromatic oil insect repellent [25].

## II. Materials and Method

### A. Universal Soil Loss Equation (USLE)

Wischmeier and Smith have developed an empirical model to predict erosion on land known as the Universal Soil Loss Equation (USLE) [26], [27]. This model is currently used as a practical guide for engineers and is still being developed in various countries. The USLE model is expressed as Equation 1.

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

In the model, erosion (E) is seen as the multiplication of 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 also tends 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.

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

### B. Rainfall

The rainfall (precipitation) data was obtained from precipitation measurements from 2007 to 2020. When this paper was written (October 2020), data for November and December 2020 were not yet available. The 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 Fig. 1.

TABLE I
Monthly Precipitation and Rainfall Intensity of Year 2007 – 2020

| Month | Monthly precipitation (mm) | | Year of the maximum precipitation |
|---|---|---|---|
| | 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 |

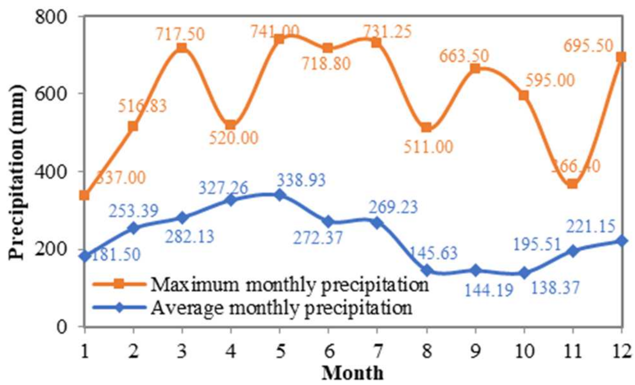


Fig. 1 Monthly precipitation plot showing average and maximum precipitation occurrence caused

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 except 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, followed by annual precipitation fluctuation with a return period of 3-4 years (Fig. 2). The end of 2020 coincides 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 [22]. The last three La Niña events in 1988, 1998, and 2010 had a 10 - 12 years return period. 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 2010.

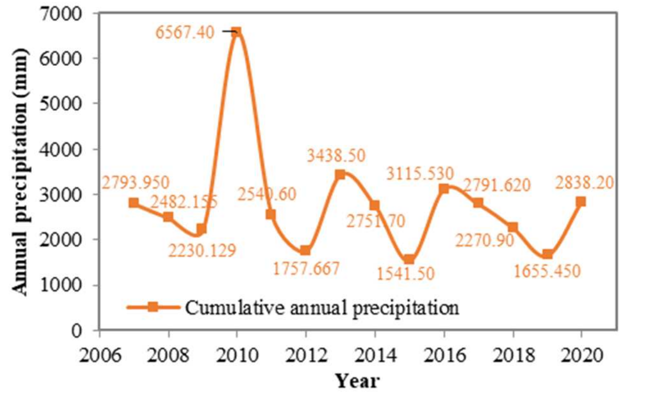


Fig. 2 Annual precipitation of the 2007 – 2020 period, showing precipitation anomaly

## 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) comes from latosol material which ranges from 0.09 to 0.27, with moderate weighting criteria of 0.22 to 0.31. Materials in the research area is consist of clay and quartz sand with low mechanical properties [27]–[30]. The sandy materials consisting of quartz minerals with the grain size of sand (0.06-2 mm) have a friction angle of 35 degrees [31]. The permeability of granite weathered soil $<10^{-7}$ cm/s [32].

## D. Topographic Factor

The length of slope (L) is measured from a location on the soil surface where the erosion begins to occur, it is a location where deposition occurs. In practice, the value of L is often calculated together with the steepness factor (S) as the slope factor (LS). Meanwhile, the classification of slope factors is shown in Table 2.

TABLE II
SLOPE FACTOR CLASSIFICATION. REPRODUCED AFTER [21].

| 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 |

Where the topography of the area in this study has a wavy topography with slopes ranging from 8-15%, in this condition, it is included in Class II with a slope factor (LS) of 1.4.

## E. Plant Cover and Preventive Measure

*Cymbopogon nardus* is the optimum plant for grass barrier [33] 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 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 [14], [24]. 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 [34], presented in Fig. 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 the ratio of erosion weight at a certain spacing control.

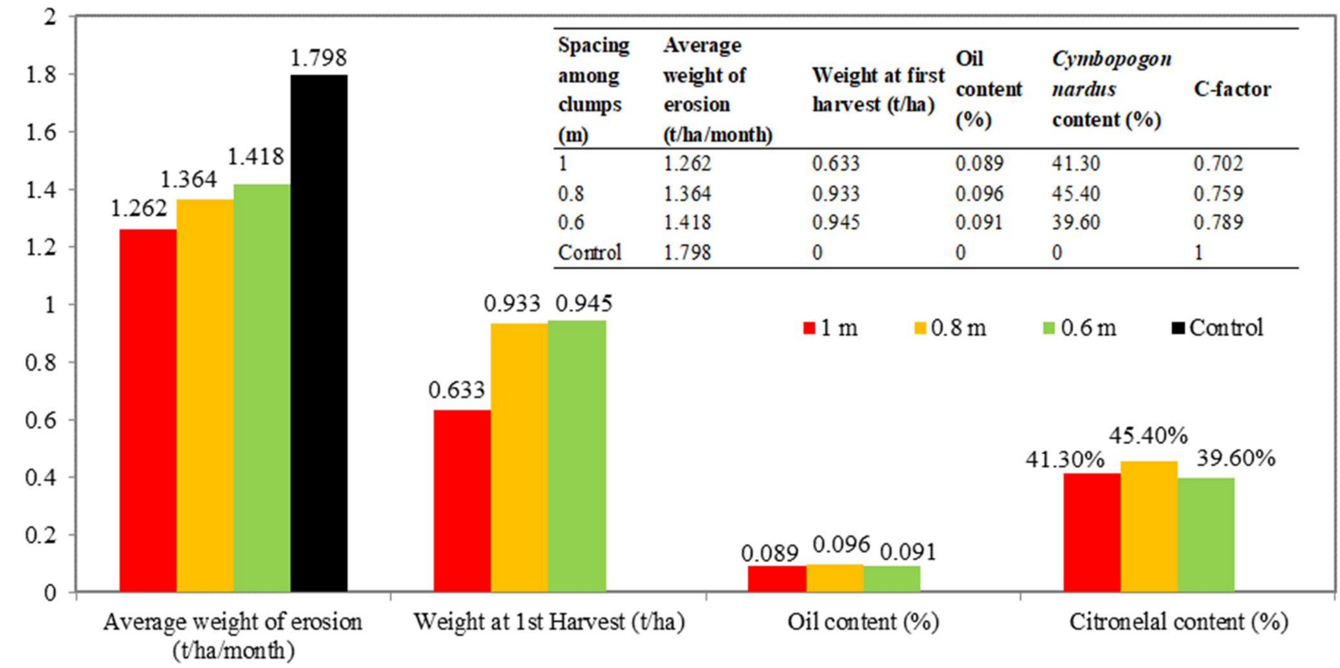


Fig. 3 Graphical representation on effect of clump spacing toward erosion, productivity, and crop quality for various clump spacing. Reproduced after [34].

Based on this study, information was obtained that planting *Cymbopogon nardus* (*citronella* grass) positively affected 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 0.8 m. The 0.8 m 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 from a staggered pattern. The planting process needs to ensure effective root growth first and then enhance 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 [24]. 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 [19].

| Slope gradient (%) | P factor |
|---|---|
| 0 – 8 | 0.5 |
| 9 – 20 | 0.75 |
| >20 | 0.9 |

## III. RESULTS AND DISCUSSION

Based on monthly rainfall data (precipitation) for 2007-2020, it is obtained that the rainfall erosivity factor (R), which is calculated by the Lenvain equation (Equation 2) from the monthly rainfall (rainfall), is then plotted per month, as presented in Figure 4 shows the monthly R factor obtained from the average rainfall (rainfall) 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 was used as the potential value of maximum rainfall and calculated to obtain the potential value of maximum rainfall erosivity factor. It is intended to serve as a consideration and reminder in design planning and maintenance scheduling due to the potential for similar anomalies in 2020-2021, marked by La Niña, which begins to occur in November 2020.

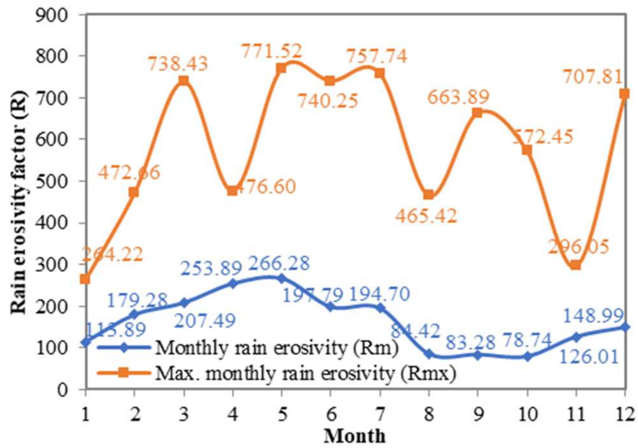


Fig. 4 Monthly rainfall erosivity and potential maximum monthly rainfall erosivity.

The average and maximum rainfall erosivity (Rm and Rmx) were calculated for each month and presented in Fig. 4. The annual erosivity Ra = 1.934 is the accumulation of the monthly erosivity Rm (January – December); while the potential value of maximum annual rainfall erosivity Ramx = 6.927 is the accumulation of the maximum monthly erosivity Rmx (January – December). The latosol material's soil erodibility factor (K) 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, it was *Cymbopogon nardus*, FAO recommends that as a plant to prevent erosion [24]. 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.

The erosion control practices can be carried out by planting in accordance with the contour pattern recommended by FAO. The erosion control factor (P) in this practice for the topography of the research area (slope 8-15%) was 0.75. A summary of 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*<br>1** | *0.8 m spacing |
| P | 0.75*<br>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 was calculated using USLE model (Equation 1). The calculation was carried out to determine monthly and annual erosion rates. The pattern of erosion that occurs every month (Fig. 5) follows the pattern of monthly rainfall (precipitation) in Fig. 1; this is under the statement that erosion is largely determined by erosivity due to rain [3], [5], [35].

Fig. 5 shows the monthly erosion rate calculated from the average monthly rainfall from 2007 to 2020 in soil conditions planted by *Cymbopogon nardus* as grass barrier and in bare-soil conditions. 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.

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

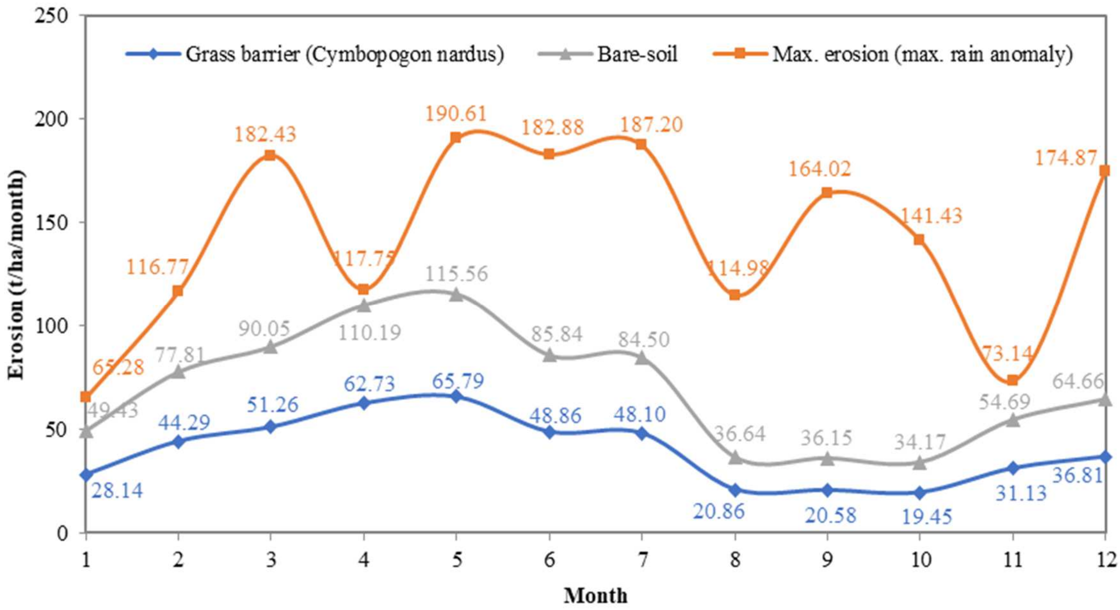


Fig. 5 Summary of monthly erosion in the research area

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 for, especially in critical lands. Moreover, indirectly, erosion due to increased rainfall has an impact on the accumulation of sedimentation in sediment ponds, and this certainly requires maintenance and operational costs that need to be considered.

This research estimates the soil volume that will be lost during the process of stockpiling, which can be used to predict the availability of soil when needed. *Cymbopogon nardus* (citronella grass) is selected due to its advantages of being not only able to maintain the quantity and quality of soil but also the economy. Thus, planting cover crops in the landfill area is considered a cost without economic value. Using *Cymbopogon nardus*, the cost to maintain the quality and quantity of soil can be taken from the *Cymbopogon nardus* cultivation. The novelty in this research is that in reducing erosion in soil stockpile area, *Cymbopogon nardus* which has economic value, can be used, so the erosion control is no longer only a cost but also beneficial.

## IV. Conclusion

Planting with a spacing configuration of 0.8 m can reduce erosion by 175.67%, which is smaller than the bare-soil condition. The value of C factor decreased from 1 to 0.75 after planting *Cymbopogon nardus* with this spacing. 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. According to FAO recommendation, the recommended cropping pattern is staggered, following the contour pattern. 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. It is annually and monthly. Awareness needs to be increased, accompanied by good preparation and planning. Fig. 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 begins 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 locations' conditions can be different from the references. More accurate data can be obtained regarding the productivity and effectiveness of *Cymbopogon nardus* planting to overcome erosion in a specific location.

## Nomenclature

| | | |
|---|---|---|
| C | vegetation cover factor | - |
| E | erosion | ton/ha/month |
| K | soil erodibility factor | - |
| L | slope length | m |
| LS | topographic factor | - |
| P | erosion control practice | - |
| p | monthly precipitation | mm |
| R | erosivity of rainfall (precipitation) | mm/month |
| Ra | annual rainfall erosivity | mm |
| Ramx | annual maximum rainfall erosivity | ton/ha/month |
| Rm | average rainfall erosivity | ton/ha/month |
| Rmx | maximum rainfall erosivity | ton/ha/month |
| S | steepness | % |

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