Spatial Prediction of Soil Erodibility Indices of the Sensitive Landscape of Bengkulu Watershed, Indonesia

Muhammad Faiz Barchia*, Bambang Sulistyo, Elsa Lolita Putri, and Welly Herman

Abstract—**Soil erodibility index (K) is a complex concept and it is influenced by many soil properties, which can reflect the soil resistance to erosion. The K index indicates soil aggregate resistency to disperse and particle transported by rainfall. Higher the erodibility index, the soil is more susceptible to erosion or in reverse. This study was aimed to show spatial feature of soil erodibility index in the fragile landscape of Bengkulu watershed conducted from July to November, 2021. Spatial analysis used some map and Landsat 8 OLI satellite imagery and ArcGIS version 10.3. The analysis depicted spatial distribution of soil textures, soil structures, soil organic matter contents, soil permeabilities and soil erodibility indices. Actually, soil organic matter content in the hilly range and undulating areas in the upper part of the watershed are categorized moderate to very high classes, however, soil texture classes in the upstream dominantly are covered by sandy loam, and loamy sand. Soil aggregate formation through the soil organic matter and soil texture binding has composed the fine and very fine granular soil structures in the upper part and in the middle part of the watershed. In the upper part and in the middle part of the watershed landscape, in fact, soil permeabilities are classified as from moderate to fast. Overlying the all inherit soil attributes, in short, the soil erodibility indices in the fragile landscape of Bengkulu watershed are not prone to precipitation detachment causing soil erosion and soil productivity deterioration.**

Index Terms—**Bengkulu watershed, inherit soil attributes, soil erodibility index**

I. Introduction

Disproportionate human tensions on the fragile landscape of Bengkulu watershed caused degradation of land productivity and human carrying capacity. The human activities related to exploited environment source on the watershed caused triggering to alleviate watersheds services for human living not only in the upstream but also in downstream, Bengkulu City. The Air Bengkulu Watershed is undergoing severe land degradation due to soil erosion [1]. Soil erosion is the major cause of soil degradation in the watershed, especially in the upstream of the Bengkulu watershed. In the hilly ranges, soils are often more exposed to erosion largely due to cultivation of the steep and fragile soils, limited recycling of dung and crop residues, poor soil management, and some parts coal mining exposures[2].

Soil erodibility is regarded as a critical parameter for evaluating the soil's susceptibility to erosion and is essential for predicting soil loss and assess its environmental effects. Soil erodibility is usually thought of as the amount of soil loss per unit of erosive force, whether it is rainfall, surface flow, or seepage [3]. The soil erodibility is expressed by the K factor [4]. The K factor is obtained by the unit plot measurement on 22.1 m in length with a slope of 9%, and it should remain uncovered, with conventional tillage along the slope [5]. Because the direct measurement of the K-value requires the establishment and maintenance of natural runoff plots for long observation periods at various locations, numerous attempts have been made to simplify the costly technique and to propose estimators for the soil erodibility calculation from readily available soil property data and standard profile description [6]. To date, the available soil erodibility calculation models, such as the USLE (universal soil loss equation) have been widely used, then upgraded by RUSLE (revised universal soil loss equation) as practical tool to predict rate of soil erosion integrated with GIS (Geographic Information System) [7].

Numerous attempts to simplify the K-factor evaluation procedure have been carried out in the past and simplified relationships have been proposed for predicting K-factor [8]. Furthermore, the procedure for determining K needs a knowledge of soil particle size distribution (PSD), soil organic matter content, and soil structure and permeability characteristics. The USLE nomograph can be used to estimate K-factor of tropical soils predominated by ferrallitic and ferruginous soils, with the exception of soils that were gravelly or covered with rocky debris that acts as protective mulch [9]. The USLE nomograph is one of the most rapid and common methods for calculating K factor based on mentioned parameters [10]. Knowledge of the spatial patterns of K-factor is vital as it might guide us to prioritize and implement site-specific soil erosion control measures and during the past decade the spatial variability and correlation of K-factor at different landscape has been intensively studied and evaluated using both classical statistics and geostatistical methods [11]. Geostatistics includes different methods that use Kriging algorithms for estimating spatially continuous variables [12]. Kriging is widely used for optimal estimation and spatial interpolation of values at unsampled locations [13]. Furthermore, the Gaussian ordinary Kriging model was more appropriate for predicting K-factor. In short, knowledge of the spatial distribution of soil erodibility is the principal mechanism for implementing practices aimed at controlling erosion. In this way, geostatistics is emerging as an alternative for the prediction of spatial variability in different environments, with the correlation of soil erodibility.

Many soil properties, including physical, chemical, biological, and mineralogical properties affect soil erodibility. K factor represents the effect of soil properties and soil profile characteristics on soil loss, recently, it has been considered as an indicator of erosion because of its sensitivity

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to detachment and transport particles. This intrinsic characteristic classified as soil erodibility is affected by soil primary particles, soil permeability, soil structure and organic matter content [14]. Furthermore, The organic matter content present in clay soils bind the particles together and thereby reducing its susceptibility to detachment and entrainment. Also, organic matter protects the soil by shielding it from the impact of falling rain and soaking up rainfall that would otherwise become runoff. Soil organic carbon has a significant effect on chemical and physical characteristics of soil and it is one of the essential components of soil quality assessment [15]. Soil organic matter contents are the principal factors that influenced soil erodibility [16]. The soil organic matter content is an important determinative item for the K-factor calculation [17]. Furthermore, by investigating the soil organic carbon (SOC) dynamics and changes of K-factor, the higher contents of the SOM in the soils were followed by the lower K-values. Organic matter in the soil reduces soil erodibility because it produces compounds that bind soil particles together, reducing the susceptibility of the soil to detachment by raindrop impact and surface run-off. In addition, organic matter increases aggregation in the soil, which increases infiltration and reduces run-off and thus erosion [18]. Any increase of soil organic matter leads to a decrease of the soil erodibility factor, it is well understood. An increase of the organic matter content will strengthen the adsorbing forces among soil particles and consequently, it will increase the soil particles resistance towards the power of running water. Maintaining the soil organic matter in high content is important for aggregate stability related to the importance for soil erodibility and sustainable soil quality.

Erodibility is high for low clay soils because non clay particles hard to mass together and form large aggregates that detachment and transport processes easily. Soil texture influenced soil erodibility where large-sized particles are resistant to haulage because of its size, while the fine particles are resistant to destructive power due to the soil cohesion factor. Particles that are less resistant to both are silt and very fine sand. There was positive correlation between soil erodibility and clay content which an increase clay content leads to increased aggregate stability and decreased erosion [19]. The soils had high sand with low silt and clay contents giving dominant textural classes of sandy loam and loamy sand suggests how the soils are well drained and easily transported by water. The soil textures mainly sandy loam, loam, clay loam and silty clay and which were more susceptible to get erosion [20].

The physical and chemical properties of the soil have been known to affect the soil stability which is an important property governing erodibility [21]. The organic and chemical constituents of the soil are important because of their influence on stability of aggregates. Soil structure defines the degree to which soil particles are clumped together, forming larger clumps and pore spaces; it influences both the ability of the soil to absorb water and its physical resistance [22]. Clay soils have a low K value and resistant to detachment. Sandy soils have low K values and high infiltration rates, reduced runoff, and sediment eroded from these soils is not easily transported. The soils with larger sand and silt proportions are more vulnerable to water erosion due to lack of stability of soil particles. In contrast, the soil erodibility potential is low for high clayey soil and coarse to medium grained granular soils [23]. The two most significant and closely related soil characteristics influencing soil erodibility are infiltration capacity and structural stability detachment [24]. Furthermore, the stable soil structures resist the beating action of rain and thereby save soil even though runoff may occur. K-factor significantly correlates with soil texture and organic matter due to their strong binding effect on aggregate stability and permeability hence enhanced particles' resistant to erosion [25].

The high intensity of agricultural activities led to the significant decrease of soil aggregate stability and permeability in the sandy clay soil which from the Universal Soil Loss Equation, the K-factor was negatively correlated with soil permeability ($r=-0.77^{**}$) [26]. Another research revealed the statistical analysis indicated negative correlations of erodibility with clay, organic matter and permeability and negative correlations of this factor with silt, sand and soil structure [27]. In short, the soil erodibility indices are quite related to soil organic matter content, clay texture class, soil structure with aggregate stability, and permeability with high pore soils.

Various researches had attentive on the measurements and effects of practical land uses because of agricultural cultivation and other land uses which had a foremost pressure on the natural ecosystems and subsequently on the Bengkulu watershed environmental services. The intensive human tension of the watershed such as for oil palm, rubber, coffee plantation by small scale farmers as well as in some upper and middle parts of the watershed for coal mining activities, has largely contributed to the accelerated rainfall driven soil erosion and consequently to the wide ecosystem services decline in the study area. Therefore, spatial continuous data of K-factor would be an important tool for implementing possible approaches for improving soil resistance in order to control erosion. At the moment, availability of information on the spatial variability of K-factors in the Bengkulu watershed is scarce meanwhile the variability of K-factor depends on the specific area. Therefore, the aims of this research were to estimate K-factor using the USLE nomograph, and assess the spatial variability of the predicted K-factor in the fragile ecosystem of the Bengkulu watershed.

II. Materials and Method

The research was conducted in Air Bengkulu watershed, Bengkulu Province from July to November, 2021. The watershed is located in Central Bengkulu regency and Bengkulu City covering 50,049ha. Geographically, the watershed lies down between 102°14'48.962" E and 102°35'5.992" E, and between 3°37'8.705" and 3°50'30.802" S [28]. Air Bengkulu watershed comprises three sub-watershed namely Susup, Rindu Hati, and Bengkulu Hilir sub-watershed [29].

Secondary data were collected in form of watershed map of Bengkulu Province with 1: 50,000 scale, soil classification map with 1: 250,000 scale, map of topographical landscape with 1: 50,000 scale, map of Bengkulu Forest Status with scale 1: 50,000 and Landsat 8

OLI satellite imagery covering Air Bengkulu watershed. Equipment needed for field survey involved compass, soil sample rings for not disturbed soils, and global positioning system (GPS). Software for data analysis used ILWIS Program version 3.4 and its hardware to process raster-based data, ArcView Version 3.3 and/or ArcGIS version 10.3 and their devices for vector-based data.

The K-value is determined by the soil texture, soil structure, hydraulic conductivity, and soil organic matter following formula [30]:

$$100K = \{2.17 \times 10^{-4} \times (12\text{-}OM) \times M^{1.14} + 4.20 \times (s-2) + 3.23 \times (p-3)\}$$

Which, **K =** soil erodibility index, **OM =** the percentage of organic matter, **s =** the class of soil structure, **p =** the class of soil permeability and **M =** $\{(\%\,\mathbf{L} + \%\,\mathbf{vfs}) \times (100 - \%\,\mathbf{C})\}$. **C** is percentage of clay (0.002 mm), **L** is percentage of silt (0.002–0.05 mm) and **vfs** is percentage of very fine sand (0.05–0.1 mm). **OM** is the organic matter content (%), p is a code indicating the class of permeability, and s is a code for structure size, type and grade based on field observation and interpreted as described by Soil Survey Staff [31]. Furthermore, the soil texture classify as follows: 1 = very fine granular, 2 = fine granular, 3 = medium to coarse granular, and 4 = blocky, semi blocky and plate. While permeability classes are grouped in six groups as described in Table I.

TABLE I: PERMEABILITY CLASS

Value	Permeabilty (cm min^{-1})	Categorized
1	12.50–25.00	Fast
2	6.25–12.50	Slightly fast
3	2.00–6.25	Moderate
4	0.50–2.00	Slightly Slow
5	0.125–0.50	Slow
6	<0.125	Very slow

K distribution pattern followed land unit map formed by over lying soil type map and slope class map. K status based on erodibility values are revealed in Table II [32].

TABLE II: SOIL ERODIBILITY INDICES

K value	Status
0.0–0.10	Very low
0.11–0.20	Low
0.21–0.32	Moderate
0.33–0.43	Fairly high
0.44–0.55	High
>0.55	Very high

III. RESULTS AND DISCUSSION

Spatial distribution of soil organic matter content is revealed in Fig. 1. Soil organic matter content in top soils at Air Bengkulu watershed dominated high to very high content which cover about 18,506.9 ha or 35.7 % and 22,225.2 ha or 42.8%, respectively, and moderately organic matter content is about 6,287.4 ha or 12.1%. The organic matter content in low to very low status covering only about 2,410.4 ha or 4.6% and 2,462.4 ha or 4.7%, respectively. Therefore, there are only about 4,872.8 ha or 9.3% of the top soil covering the Bengkulu watershed prone to agregate disperse enhancing soil degradation because of erodibility index raise (see Fig. 1).

Soil types covering Air Bengkulu watershed are dominated by inceptisols and ultisols which are fragile to degrade by rainfall attachment. Spatial distributions of the soil texture clases are shown in Fig. 2. The upstream of the watershed with the hilly landscape occupy dominated by sandy loam, 11,175.4 ha or 21.5% and loamy sand, 8,269.5 ha or 15.9% while on the middle stream of the watershed with undulating landforms covering by the soil textures of clay loam, clay, and sandy clay loam with areas are 16,799.8 ha, 2,462.4 ha, and 6,408.4 ha or 32.4%, 4.7%, and 12.3%, respectively. The soil textures dominated in the downstream of the watershed are loam and 6,172.7 ha or 11.9% and silt, 604.2 ha or 1.2%, and some sandy loam and sandy clay loam especially areas closed to Bengkulu river (see Fig. 2).

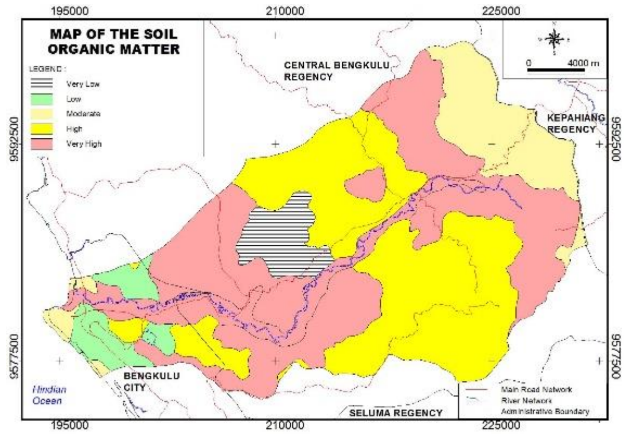

Fig. 1. Spatial distribution of organic matter map.

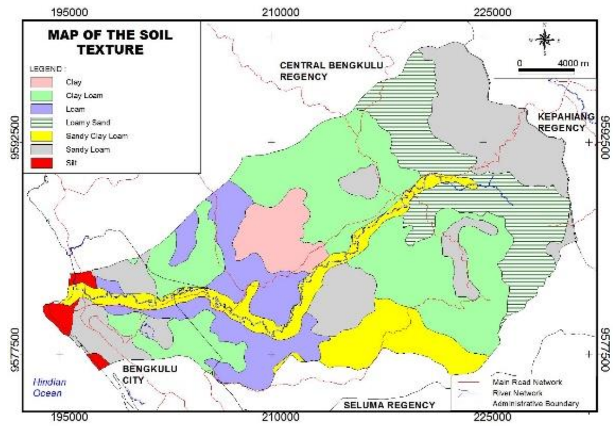

Fig. 2. Spatial distribution of soil texture map.

Soil structure stability is an important attribute to prevent water infiltration and water holding capacity to keep the landscape productivity in the Air Bengkulu watershed. Preventing soil structure from degradation implies a maintain in soil quality with an attendant promote in ecosystem functions and services. Spatial feature of soil structure in the topsoil covering the Air Bengkulu watershed was depicted on Fig. 3. The soil aggregates forming the soil structures on the top soils of the watershed landscape dominantly consist of very fine granular to fine granular covering 24,881.0 ha or 47.9% and 20,638.3 ha or 39.8%, respectively. The soil structures covering the landscape of the Bengkulu watershed actually dominantly are prone to water detachment by precipitation and run off therefore the landscape of the watershed should be covered by permanent vegetation (see Fig. 3).

The spatial distribution of the soil permeability indices is shown in Fig. 4. Following the figure, the moderate to fast permeabilities classes cover about 31,006.6 ha or 59.8% of the area while slow to moderate permeabilities groups cover about 20,885.8 ha or 40.2%. The moderate to fast classes of the soil permeabilities indices lies on the upper parts of the Bengkulu watershed while the slow to moderate classes cover on the downstream and some parts of the middle stream of the watershed. These indicate that mostly in the upper stream of the watershed are still covered by permanent vegetation such as secondary forests and agroforestry with coffee cultivation (see Fig. 4).

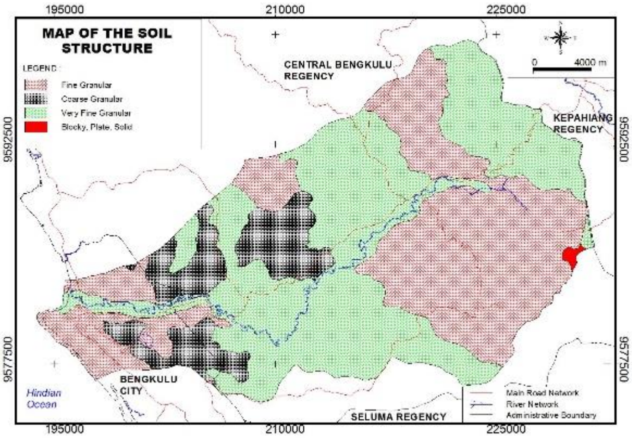

Fig. 3. Spatial distribution of soil structure map.

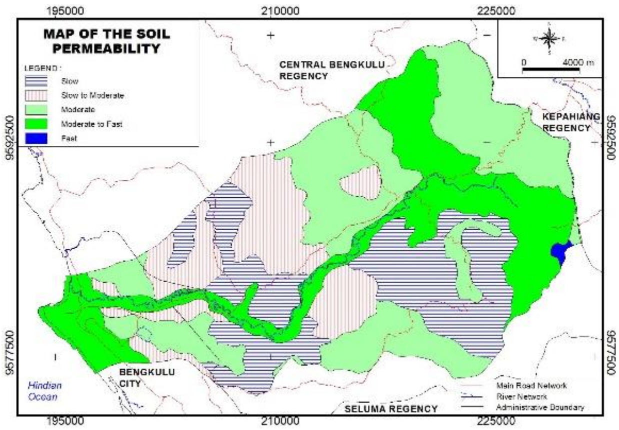

Fig. 4. Spatial distribution of soil permeability map.

The upstream of the watershed with the hilly landscape occupy dominated by sandy loam and loamy sand while on the midle stream of the watershed with undulating landforms covering by the soil textures of clay loam, clay, and sandy clay loam. In this case, the inherit properties based on the soil particle actually in the middle stream of the Bengkulu watershed are more susceptible to disperse because of precipitation and run off than those in the upstream of the watershed.

In fact, the soil structures on the top soils of the Bengkulu watershed mostly compose of very fine granular to fine granular fragile to water detachment by precipitation and run off to promote soil erosion. The spatial distributions of the soil permeability in the Bengkulu watershed show the moderate to fast permeabilities classes mostly in the upper stream while slow to moderate lying on the middle and down stream of the watershed.

Soils with slow permeability, high sand and silt content, and medium- to fine-grained soil structures are the most erodible. In fact, the soil erodibility indices in the top soil of the Bengkulu watershed show about 34.4% of the area are classified as slightly high in erodibility indices, and about 64.0% are involved as moderate classes. In general, soils in this watershed are prone to degradation because of soil erosion related to medium to slightly high values of erodibilities indices. In this case, the organic matter contents in the top soil of the Bengkulu watershed relatively high however the soil structure with very fine granular to fine granular combined with the soil textures of sandy loam and loamy sand causing the soils on the Bengkulu watershed landscape are prone to water detachments by precipitation and run off because of the moderate to high values of the soil erodibility indices.

IV. CONCLUSION

The air Bengkulu watershed today under pressure because of human activities for agricultural cultivation such as oil palm, rubber, and coffee plantation by small scale farmers, coal mining exploitation, and development of infrastructure facilities. These human activities related to exploited environment source caused triggering to alleviate watersheds services for human living not only in the upstream but also in downstream. Actually, the environmental properties especially the landscape are covered by fragile soils and the soils would face with poor degradation when land cultivation in appropriate managements. The land degradations would occur mainly due to soil erosion on the over exploited landscape. The most significant and closely related soil characteristics influencing soil erosion is the soil erodibility as a function of soil organic matter content, soil texture, soil structure, and permeability index. Although the organic matter content in the top soils of the landscape relatively high, inherit characteristics of soil texture determining soil structure and permeability result in moderate to high erodibility indices. Generally, the Bengkulu watershed is prone to alleviate its productivities because the soils are erodible by precipitation and run off detachments.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Muhammad Faiz Barchia: Designed the research plan, participated in all experiments an contributed to the writing of the manuscript.

Bambang Sulistiyo: Verifed the analytical methods, analyzed the data.

Welly Herman: Carried out the experiments

Elsa Lolita Putri: Coordinated the mouse work.

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