Erosion Potential Based on Erodibility and Plasticity Index data on Cilengkrang, Bandung, West Java, Indonesia

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Abstract. Cilengkrang is a sub-village in the north of Ujung Berung and Cijambe sub-District Bandung Regency, Indonesia. It is located on the west of Cikeruh sub-watershed. This subwatershed is part of greater upstream Citarum watershed. This area has been developed rapidly by new settlement and villa. However, the available data of erosion potential in this area is less convenient. The erosion is a severe problem that has a strong relation to flood potential. This study starts with collected engineering geological data from 14 samples. These samples were taken from different soil types from its engineering characteristics. Based on the field and laboratory observation, this area is form by fine-grained soils as a result of residual soils from young volcanic rocks — the silt and very fine sand content range from 49 to 70 % of the total soil. The erodibility value (K) in this area is from 0.03 to 0.06. These values are indicating moderate soil erodibility class. The plasticity index (PI) also shows value from 9 to 48 %. This value is pointing low to high plasticity behavior of this soil. The regression linear shows strong correlation between PI and K with r = 0.7. This correlation is interpreted that the cohesion controls the soil characteristic in Cilengkrang area and affect the moderate erodibility value. This study hopefully giving new insight that soil mechanic data is can also support data on erosion potential.

Keywords: Erodibility, Erosion Potential, Plasticity Index, Cilengkrang

1. Introduction

The erosion is a severe problem that has a strong relation to flood potential. Land degradation from forest to housing complex development, are some factors that lead an accelerated erosion. This accelerated erosion will also affect the decreasing water infiltration area during the rainy season. One of the well-known methods to predict this soil erosion is USLE (Universal Soil Loss Equation) proposed by Wischmeier and Smith in 1978 [1]. However, soil erosion prediction is a complex and multifaceted process that is affected by a host of factors. 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 [2]. The soil erodibility is expressed by the K factor. This 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 [1,3]. While the Plasticity Index (PI) is a measure of the plasticity of a soil. It is also the difference between the liquid limit and the plastic limit of soil [4]. The higher the value of the PI, the more soil is plastics. The soil has potential to adsorbed water in significant number, by its cohesion due to the clay mineral. However, the lower
value of PI, indicating that the soil has less cohesion and more silt characteristic. Since the silt is the high erodible material \([5–7]\), the lower PI value would correlate with the erodibility factor.

The area of the study is located in Cilengkrang area. This area is a sub-village situated on the north of Ujung Berung, Bandung City, and close to Cijambe sub-District Bandung Regency, West Java Indonesia. This area is developed rapidly in housing complex development because of the strategic location near to Bandung capital city. Cilengkrang is located on the western part of Cikeruh sub-watershed. This subwatershed is part of greater upstream Citarum watershed. Several studies about erosion have done in Citarum watershed. However, most of them are studied in the southern part of this watershed, such as Subardja et al. \([8]\) and Sukiyah et al. \([6]\) focused on the south of basin of Bandung. However, there is also research on erosion potential in Bandung Basin, such as Saptari et al. \([9]\) and Apandi \([10]\) in Citarik sub-watershed. However, this research is studied by remote sensing analysis. Thus this paper will give a new insight by using field samples to determine the erodibility class. A previous study is did in a similar weathered volcanic material in Jatinangor area, Sumedang West Java by Khoirullah and Sophian \([11]\). This study showed that Jatinangor is consist of a high silty material in weathered volcanic material. This study also showed that the erodibility class in Jatinangor is categorized medium to high. Since weathered volcanic materials also form the Cilengkrang area, this study will present a wider result of erodibility data in weathered volcanic rocks. The rapid development in Cilengkrang area is present by many the housing complex built that changing the previous agriculture land. The decreasing green open space would lead a high erosion potential \([12]\).

However, erodibility data is less available. Whereas by identify the erodibility data, we find out that an area would have higher erosion potential if left bare. Since the soil also has physical and mechanical properties, it would be indicated that these both parameters would have a significant correlation to the engineering geological data. This paper aims to show the relationship between the soil erodibility and the plasticity index value. Moreover, this paper will add new data collaboration. If we had PI data, it also could be used to identify the erodibility factor. Furthermore, the developer on the infrastructure in Cilengkrang will even think of the solutions to the impact of land clearing. The omission of this problem is feared could increase erosion rate that causes flash flood potential in East Bandung.

2. Method and Materials

This study started with field mapping to identify the surface condition of the soil. After that, the hand auger or hand boring test is done to obtain the shallow subsurface characteristic of soil. By the depth of 0.5 meters, the undisturbed sampling is done. There are 14 sites chosen by random sampling after the soil mapping result came. Later, the samples are tested in the laboratory to obtain grain size analysis, hydrometer analysis, and also Atteberg Limit test. The grain size analysis resulted in the percentage particle size, such as sand, silt, and clay. And the Atteberg limit tests were Liquid Limit test and Plastic limit test. These both test will result in plasticity index (PI) formula \([13]\) shown as

\[
\text{Plasticity Index (PI) = Liquid Limit (LL) – Plastic Limit (PL) \ldots(1)}
\]

While the soil erodibility is using Wischmeier and Smith formula \([1]\) shown as

\[
100 K = \{ 2,1 M^{1,14}(10^{-9}) (12 – a ) + 3,25 (b – 2 ) + 2,5 (c – 3 ) \} \ldots(2)
\]

where

\[
K = \text{Soil erodibility}
\]

\[
M = \text{Particle Percentage (% of very fine sand + % of silt x (100 - % clay))}
\]

\[
a = \text{percent organic matter content}
\]

\[
b = \text{soil structure code used in soil classification}
\]

\[
c = \text{the soil profile permeability class}
\]

However, this K unit of short US Dimension \((0.1\text{-ton acre hour/acre foot-ton inch})\). The K factor values obtained by the equation or nomograph constructed with the parameters must be multiplied by a factor of 0.1313 to be able to express the results in the International System of Units \((\text{metric ton hectare hour/hectare megajoule centimeter})\) \([3]\). The M factor is obtained by grain size and hydrometer analysis test. While the a, b, are collected by field observation. And the c factor is achieved by the permeability test.
3. Results and Discussion

Based on the field observation Figure 1, the high plasticity fine-grained soil is dominating in Cilengkrang area. This soil has brown to reddish-brown color, soft strength, and medium to high plasticity. This soil is interpreted as the weathered product of young and old volcanic materials, according to Djadja and Hermawan previous research published on the Engineering Geological Map of Bandung Quadrangle [14].

![The Tuff rock and its weathering zone to brown soil (photo taken by Arif F. Sobari and team)](image)

After the field observation, the samples are taken and test on the laboratory. In order to obtain the quantitative grain size distribution, the samples are tested with sieve analysis. The percent pass of mess 200 is categorize to fine grain soil. To determine the silt and clay distribution, the sample are test with hydrometer analysis. The summary of the distribution percentage of soil can be seen in the Figure 2.

![The distribution of soil percentage from 14 samples taken in Cilengkrang area](image)

From figure 2, it can be seen that the silt and clay are dominating in all 14 samples with range 66 %— 92 %. This is indicating that there are no significant differences between residual soil source from breccia nor tuff. Likewise, there is no differences between silt and clay percentage. Except for sample number 12, that shows the sand percentage is more significant than the clay percentage. This grain size distribution is used to determine the K factor. the soil later analyzed by the erodibility characteristic. the summary of the erodibility can be seen below. The a factor is based on field observation and assumption, if the soil is left in bare condition with less organic materials. The b factor is based on the field observation, the soil condition is likely blocky and massive. While the c factor is based on the falling head of permeability test on the laboratory. The summary of erodibility factor is described on the Table 1.
Based on Table 1, the erodibility in Cilengkrang are range from 0.03 to 0.06 t ha h ha-1 MJ-1 mm-1 in SI units. From this results, the erodibility class according to Foster et al.[15] in Cilengkrang is categorized into moderate soil erodible except on sample 12 that categorize into high soil erodible. This means that the soil in Cilengkrang soil has susceptibility to detachment and transport by erosion process, especially by rain [1,3,16].

After testing the grain size analysis, the samples then test with Atteberg limit to obtain the plasticity characteristic. The summary can be seen on the Table 2.

### Table 1 The summary of erodibility in Cilengkrang

| Sample Code | Very Fine Sand (%) | Silt (%) | Clay (%) | a | b | c | K erodibility in US unit | K erodibility in the SI unit |
|-------------|--------------------|----------|----------|---|---|---|-------------------------|-----------------------------|
| 1           | 0.64               | 64.705   | 26.155   | 3 | 4 | 4 | 0.32                    | 0.055                       |
| 2           | 2.12               | 47.74    | 43.16    | 3 | 4 | 3 | 0.19                    | 0.033                       |
| 3           | 2                  | 53.52    | 38       | 3 | 4 | 4 | 0.24                    | 0.042                       |
| 4           | 1.8                | 63.205   | 31.595   | 3 | 4 | 4 | 0.30                    | 0.051                       |
| 5           | 1.4                | 56.13    | 39.67    | 3 | 4 | 4 | 0.25                    | 0.042                       |
| 6           | 1.26               | 60.675   | 36.205   | 3 | 4 | 3 | 0.25                    | 0.042                       |
| 7           | 1.26               | 47.955   | 48.925   | 3 | 4 | 4 | 0.20                    | 0.034                       |
| 8           | 0.56               | 53.195   | 44.325   | 3 | 4 | 4 | 0.22                    | 0.038                       |
| 9           | 2.3                | 50.4     | 42       | 3 | 4 | 4 | 0.22                    | 0.039                       |
| 10          | 1.82               | 67.915   | 24.286   | 3 | 4 | 4 | 0.34                    | 0.059                       |
| 11          | 2.82               | 61.47    | 30.73    | 3 | 4 | 4 | 0.30                    | 0.051                       |
| 12          | 6.1                | 59.35    | 6.67     | 3 | 4 | 3 | 0.35                    | 0.061                       |
| 13          | 1.48               | 60.17    | 31.67    | 3 | 4 | 4 | 0.28                    | 0.049                       |
| 14          | 2.8                | 52.49    | 38.67    | 3 | 4 | 4 | 0.24                    | 0.042                       |

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### Table 2 The summary of Atteberg Limit test

| Sample Code | Liquid Limits % | Plastic Limits % | Plasticity Index % | Description        |
|-------------|-----------------|------------------|--------------------|--------------------|
| 1           | 85              | 50               | 35                 | High Plasticity    |
| 2           | 82              | 41               | 41                 | High Plasticity    |
| 3           | 74              | 35               | 39                 | High Plasticity    |
| 4           | 76              | 34               | 42                 | High Plasticity    |
| 5           | 83              | 35               | 48                 | High Plasticity    |
| 6           | 81              | 46               | 35                 | High Plasticity    |
| 7           | 90              | 46               | 43                 | High Plasticity    |
| 8           | 88              | 55               | 33                 | High Plasticity    |
| 9           | 72              | 29               | 43                 | High Plasticity    |
| 10          | 50              | 34               | 16                 | Medium Plasticity  |
| 11          | 47              | 29               | 18                 | High Plasticity    |
| 12          | 89              | 80               | 9                  | Medium Plasticity  |
| 13          | 95              | 62               | 33                 | High Plasticity    |
| 14          | 67              | 36               | 31                 | High Plasticity    |

Based on the Table 2, the plasticity characteristic of 12 samples are categorized into high plasticity, and only two samples are medium plasticity feature. The greater value of the plasticity index (PI)
indicates that the soils have clayey behavior instead of silty expression. It is also concluded the clay mineral type form this soil has high cohesion value like illite mineral. While the samples on code 10 and 12 indicated the silty clay characteristic. This soil still has cohesion due to the clay mineral. However, the clay mineral type could be dominated by kaolinite.

Based on both erodibility and plasticity index data, the relationship is made between the plasticity index and erodibility factor can be seen on Figure 3.

Based on the graphic above, it can be concluded that the plasticity index has a strong correlation to erodibility factor. This is interpreted as similarity behavior of the soil. The high erodible soil will have a lower value of PI. This would be a useful information for geotechnical or civil engineer before developed an area for a housing complex. If the erodible data are not available, the plasticity index can be a solution to estimate the soil characteristic. If an area has a lower PI value, that means the soil characteristic on that site is highly erodible. To prevent the erosion potential of the soil loss, the geotechnical engineer co-work with agriculture scientist by several solutions, e.g. with the movement of planting erosion-retaining plants. The simple prevention on the upstream management would prevent a flood disaster on the downstream.

4. Conclusion
The Cilengkrang area is consist of medium to high plasticity fine-grained soil it is strongly correlated to the erodibility factor, from moderate soil erodible to high soil erodible. It can be concluded that the geotechnical data like plastic limit (PI) can be used to identify the erodibility factor. The developer needs to concern for not left the land barely especially during the rainy season, since the Cilengkrang soil has prone to erosion. Further work should be adding more samples to obtain a more accurate analysis.

5. Acknowledgments
The author also would like to thank Cilengkrang team, Arif F. Shobari, Annisa Ayuningtyas A.P., Iqbal J. M. and Aldi Rexy for assisting the field data. This article’s publication is partially supported by the United States Agency for International Development (USAID) through the Sustainable Higher Education Research Alliance (SHERA) Program for Universitas Indonesia’s Scientific Modeling, Application, Research and Training for City-centered Innovation and Technology (SMART CITY) Project, Grant #AID-497-A-1600004, Sub Grant #IIE-00000078-UI-1. The research was funded by Indonesian Ministry of Research, Technology and Higher Education (Ristekdikti) under the scheme of University Basic Research Excellent 2019 Contract No. NKB-1636/UN2.R3.1/HKP.05.00/2019.


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