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Research Article

Determination of Soil Erodibility Index for Taiwan Mountainous Area

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Abstract: Rainfall in Taiwan mainly concentrates in the period of typhoons and torrential storms. In this period the soil severely erodes due to the frail geology, steep gradient and easily weathered parent rock. Currently, the Universal Soil Loss Equation (USLE) is used to estimate soil erosion amount in Taiwan. Although it is regarded as the reference, its results are often inconsistent with the actual situation because the application conditions show great difference. Therefore, an alternative to the USLE is necessary for Taiwan. This study focused on 25 main basins in the mountainous area of Taiwan from which 69 experimental sites were established; 20 in the north, 11 in the center, 21 in the south and 17 in the east. The agency of Soil and Water Conservation Technical Specifications table, soil test in the experimental site and on-site measurements of erosion and redeposition were used to determine soil erodibility index (Km). The results shows that most Km obtained in the north areas were smaller than those from the specification, while Km in the rest of the areas varies without a regular pattern. It was concluded that the Southern areas were more susceptible to soil erosion because of the larger indexes.

Keywords: Soil erosion, soil Erodibility index, Taiwan mountainous area, universal soil loss equation

INTRODUCTION

Taiwan is an island covering 3.6 million hectares, of which, about 2.639 million hectares are mountains, accounting for 73.3% of the total area. Hence, it is inevitable to develop and use these mountainous areas. Influenced by the topography, rainfall distribution is uneven and mainly concentrates in the typhoon season. In addition, the steep gradient and frail geology makes the soils of Taiwan to erode severely. How to control soil loss and reduce soil erosion is a key subject for soil and water conservation when developing these mountainous areas.

The Universal Soil Loss Equation (USLE) is currently the most popular empirical model in many countries to estimate soil erosion amount (Shi *et al*., 2004). Soil erodibility (Km) is one of six factors affecting soil erosion in the USLE that reflects the ease with which soil is detached by splash during rainfall, surface flow or both (Renard *et al*., 1997). The soil erodibility is commonly predicted using the USLE nomograph on the basis of five soil and soil profile parameters that include soil particles (% sand, % silt, % very fine sand and silt and % clay), % organic matter, soil structure code and soil permeability class (Schwab *et al*., 1993). The parameters in this equation were representatives from two-thirds of the eastern U.S. As time elapsed, the accumulated data shaped this equation that has been widely employed in today's research.

Taiwan is not an exception among the countries using the USLE. It is still the main method to estimate soil loss and is in the Technical Code of Soil and Water Conservation and Manual of Soil and Water Conservation as the reference for the country. However, its results are often inconsistent with the actual situation because the application conditions show great difference (Huang *et al*., 2012).

Proper evaluation of main eroding factors in an area of interest and determination of their variations in space should be taken into account in choosing a strategy for controlling erosion in critical areas (Rejman *et al*., 1998). Factors like rainfall erosion index, gradient, slope length, crop management and conservation practice (R, L, S, C, P) have been modified by scholars based on related data, but the Soil Erosion Factors (SEFs) still lacks a suitable equation for local conditions. This is attributable to the limited field data and survey and to the time-consuming process for estimating Km on site. As a result, Km is still estimated based on the basic property of soil and the Km varies spatially according to these soil properties (Vaezi *et al*., 2010). The considerable differences between the measured and estimated values of soil erodibility indicate the necessity for appropriate modifications to adapt this USLE monograph for tropical soils (Vanelslande *et al*., 1984).

For this reasons, this study focuses on the 25 major basins of Taiwan and selects the unexploited slope surfaces to set the test areas for measuring depth of soil

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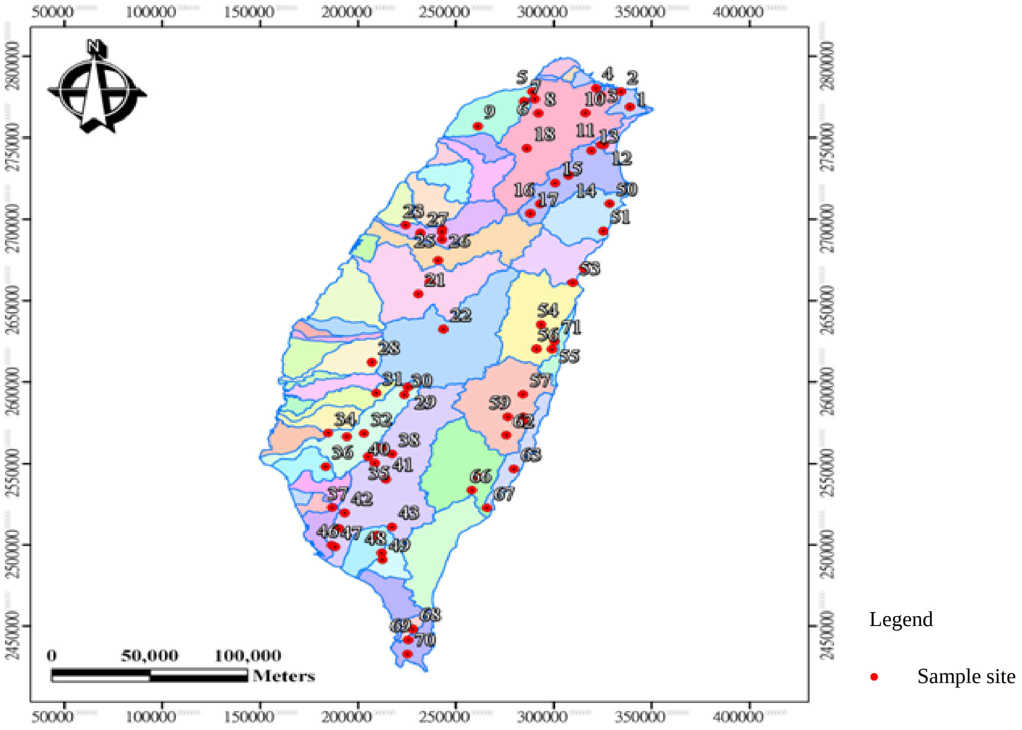

Fig. 1: A map showing distribution of the sampled sites

erosion. Sixty-nine experimental sites are set up in total all over Taiwan to learn the features of soil erosion and improve the accuracy of estimating soil erosion amount.

This will serve as the reference for estimation of soil loss in the planning program of the Soil and Water Conservation projects in future.

MATERIALS AND METHODS

Study site: To investigate soil erodibility factor, this study focuses on 25 main basins throughout Taiwan to measure the soil erosion depth in the period 2009 to 2011. From the basins 69 experimental sites were established; 20 in the north, 11 in the center, 21 in the south and 17 in the east. The basins (indicated by the different colors) and the 69 experimental sites that were established are shown in Fig. 1.

Study method: Types of experimental site: The size of the plot was determined by in-situ conditions: the slope length (longitudinal) of 10 m and the slope width (horizontal) of 2 m (Fig. 2). Establishment of erosion stake: At every 2 m in the horizontal section, five erosion stakes were installed, that is, 1 stake per 0.5 m. longitudinally, the slope was divided into 2.5 m-five sections. Totally, twenty-five stakes were set up in each experimental site (Fig. 2). The erosion stakes were round steel bars with a diameter of 3 and 30 cm length. The top 5 cm was painted in red while the remainder was dug into the soil (Fig. 3).

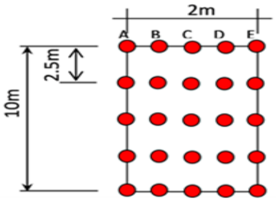

Fig. 2: Layout of each plot

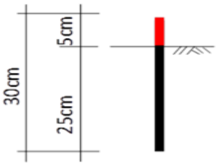

Fig. 3: Erosion stake

Establishment and measurement of experimental sites: When setting up the experimental sites, we drove all stakes into the soil with a special sleeve, which was manufactured accurately by lathe with a depth of 5 cm. The contact between the sleeve and soil surface indicated a protrusion of stake by 5 cm. In addition, we used a venire caliper to measure the height from the top of the stake to the ground surface, which was taken as the initial depth measurement. After establishing the experimental site, we employed a laser level to carry out subsequent height measurements. We measured the elevations top of each stake and recorded it as the visual height and determined the ground height by subtracting

Table 1: Categories of soil structure index

Structure category	Soil structure	Particle size (mm)
1	Very fine particles	<1.0
2	Fine particles	1.0~2.0
3	Medium or coarse particles	2.0~10.0
4	Blocks, shale or coarse particles	>10.0

Table 2: Categories of soil infiltration index

Infiltration category	Infiltration	Infiltration rate (mm/h)
1	Very fast	>125.0
2	Fast	62.5~125.0
3	Medium	20.0~62.5
4	Medium to slow	5.0~20.0
5	Slow	1.25~5.0
6	Very slow	<1.25

visual height from measurement depth. After setting up the soil experimental sites in the slope, soil hardness nearby was measured. After which, five kilograms samples were taken to the laboratory for gravity test, color test, sieve analysis and the organic carbon content test.

Estimation methods of soil erodibility index: Nomographs of soil erodibility index: In the analysis of Nomographs, two observations were made. First, the size of soil particles had very fine sand and included silt. This resulted to an improved estimation of soil erodibility index (Km) for sand and silt. Secondly, the index obtained from the Nomographs was rough and inaccurate.

Equation of soil erodibility index: Equation proposed by Wischmeier *et al*. (1958):

$$100\,K = 2.1M^{1.14} \cdot 10^{-4}(12 - a) + 3.25(b - 2) + 2.5(c - 3) \qquad (1)$$

$k =$ ton. acre.hr/100.acre.feet.ton.in

where, K is the soil erosion index in Imperial Units which can be multiplied by 0.137 when converting into metric system, namely, Km = 0.1317k.

M = Silt and very fine sand (0.002-0.1mm) % x (100%-silt %).
a = Percentage of organic content (regarded as 4% when it is larger than 4%)
b = Soil structure index (Table 1)
c = Soil infiltration index (Table 2)

Table of soil erodibility index: Wann and Hwang (1989) employed the nomographs of Wischmeier *et al*. (1958) to estimate the Soil Erosion Factors (SEFs). They used data collected from 280 sites around Taiwan based on the number of rows of Wischmeier and Smith (1965). They compiled a table, from which the Km in this study was obtained.

On site determination using approximate soil erodibility index: Soil Conservation Service (1978) developed a table of soil erodibility index in 1978 to facilitate the conservation engineers in determining the soil erodibility index on site. This table is only applicable for in-situ soil properties and yield approximate index.

RESULTS AND DISCUSSION

The basins and the distribution range of soil erodibility indexes: The soil erosion indexes (Km) of each experimental site were analyzed to determine the distribution range and are presented in Table 3 and Fig. 4. The results show that the soil erodibility indexes of each basin ranged from 0024~0.0876, of which the Tsengwen basin had the highest index, indicating a weaker erosion resistance in the area.

This study also used the erosion indexes defined in the Technical Code of Soil and Water Conservation, as shown in Table 3, to analyze and compare it with the data obtained through experiment and analysis in this study. The comparison showed no regular pattern between the experimental data and the defined data and the indexes in each basin ranged from 0.01~0.06. Only the Tsengwen and Yanshuei basins in the south area had an experimental index larger than 0.07, indicating that the soil erodibility index in the south area of Taiwan is relatively large. Hence, the soil erosion resistance is weak.

In terms of distribution, the experimental indexes in the basin of Tsengwen basin had the widest range, from 0.018 to 0.0876. This indicates that the difference of soil erosion resistance in this area is large and its lowest value of 0.018 is still larger than that of other areas (0.01). This also shows how the area of Tsengwen basin has a weaker erosion resistance than others.

Soil texture and soil erodibility index in Taiwan: In general, the soil erodibility should be in reverse proportion to the soil texture, that is, the coarser the texture, the higher the soil erodibility and the lower the soil erosion index. This is so because the particle size of sandy loam is large with a heavy texture, hence, the pores are large enough to increase infiltration rate and reduce runoff, subsequently soil erosion. On the other hand, the particle size of clay loam is smaller with a lighter texture; hence, the pores are smaller to reduce infiltration. The on-site experimental results of the soil erosion index were compared to the soil erosion index developed by the USDA-SCS in 1978 and the results are shown in Table 3 and Fig. 5. The ranges of the indexes in different soil textures in Taiwan are wide and all the maximum indexes are larger than the indexes defined by the USDA-SCS. This indicated that the soil textures of Taiwan had a large variability and the soil erosion resistance may be weak. The soil erodibility indexes in different soil textures followed the order, from the highest to lowest, silty clay, sandy loam and gravel.

Table 3: Comparison between the Km defined by USSCS and those obtained by this study

Surface soil texture	Km value defined by USSCS	Km value obtained by this study
Clay loam; clay loam; loam; silty clay	0.042	0.056~0.0056
Fine sandy loam; loamy fine sand; sandy loam	0.032	0.05~0.0082
Loamy fine sand; loamy sand	0.022	0.0287~0.0084
Sandy loam	0.020	0.0253~0.0024
Silty loam; Silty clay loam; very fine sandy loam	0.049	0.0876~0.0058

Table 4: Comparison between the norm and the experiment Km in different land utilization

Land utilization	Km value in norm	Km value in this experiment
Shenmu Forest	0.0579~0.007	0.071~0.0024
Exposed landslides of bamboo forest	0.0053	0.0081
Orchard	0.0474~0.0117	0.0164~0.0059
Grassland	0.0553~0.0117	0.0876~0.0069

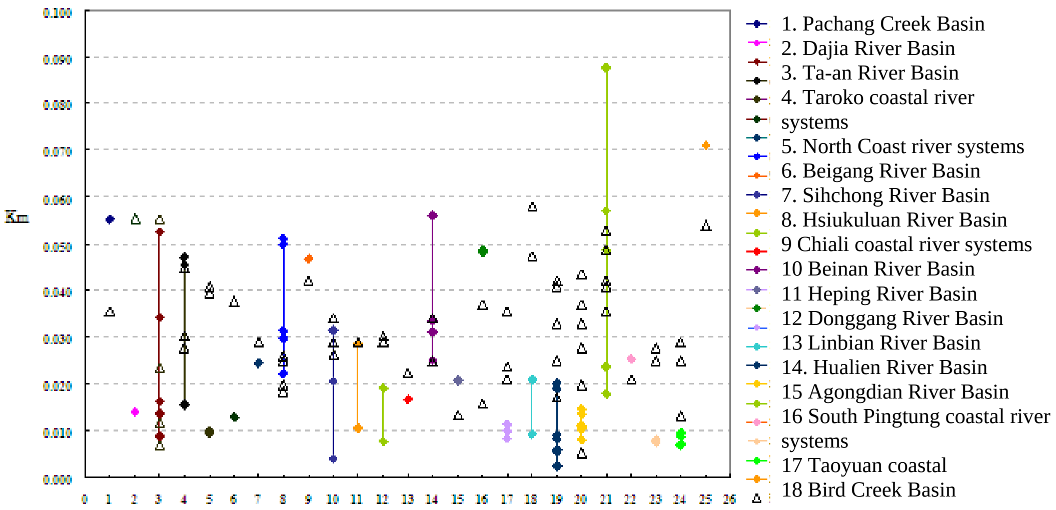

Fig. 4: Distribution of soil erodibility index in each basin of Taiwan

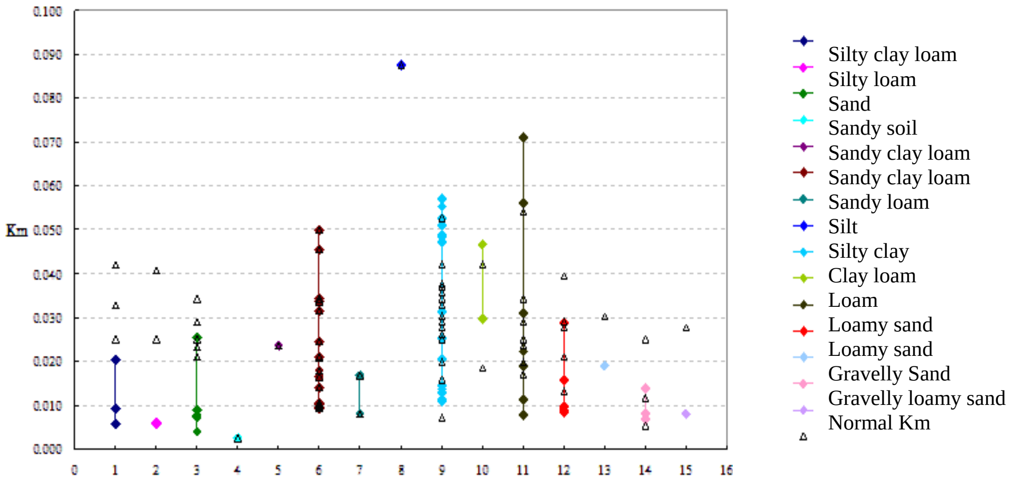

Fig. 5: Distribution of soil erodibility index in each soil textures of Taiwan

Moreover, the index values of most gravels were lower than 0.02 and the sandstone were lower than 0.03. Only the sandy clay loams had relatively higher indexes and wider range from 0.01 to 0.05.

Soil erodibility index and land utilization: Table 4 and Fig. 6 illustrate the comparison results of soil erodibility index values between the experimental results and the norms in different land utilization types. The results showed that the index from Soil and Water Conservation Specification (norms) were larger than the experimental ones in the orchard land utilization type. This was opposite to the rest utilization types.

Moreover, in the utilization types of woodland and grassland, the index range in the experiments were also wider than that of the specification.

Further investigations revealed that the indexes are evenly distributed in the norm, some of which are centralized as shown by the experimental results. For example, the experimental index in Shenmu Forest can be generally divided into three types of central tendency, in which the values are between 0.055~0.045, 0.035~0.02 and 0.015~0.005; two central tendencies are found in the Grassland, namely, indexes between 0.06~0.04 and 0.035~0.015.

All land utilization types except landslides contain a large number of variances, leading to more variables affecting soil erosion resistance. Although the experiments are conducted in the same fields of Shenmu Forest, Orchard and Grassland, it is hard to evaluate the differences of soil erodibility index in the different sites due to the wide range of soil erodibility index values. However, in the landslide where the

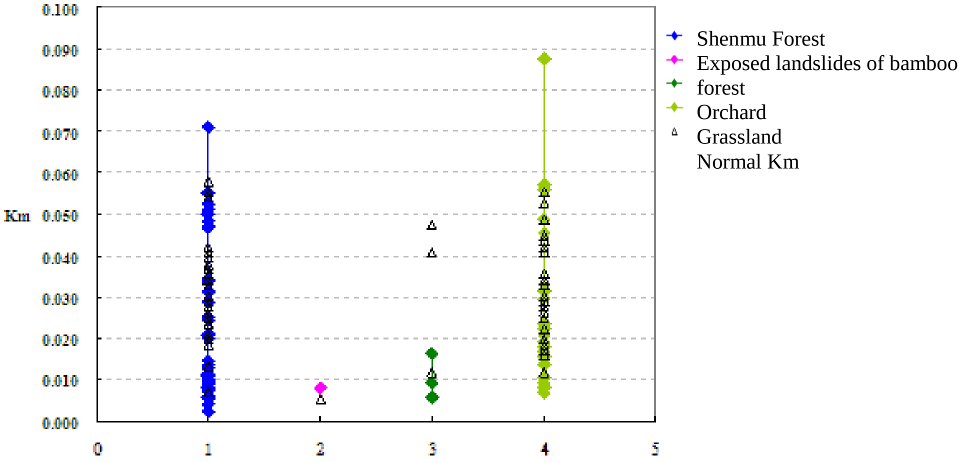

Fig. 6: Distribution range of the experimental Km for different land utilization

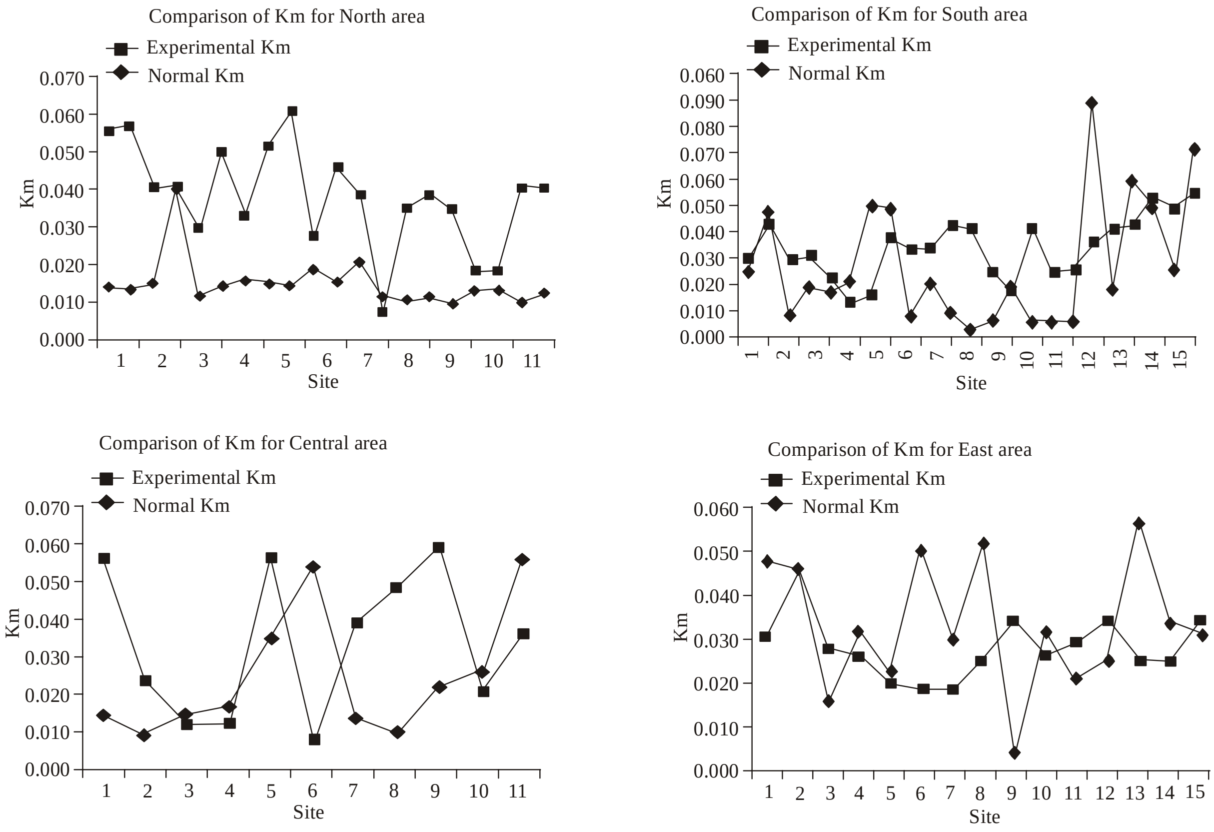

Fig. 7: Comparison between the experimental Km and specification (normal) Km

variances are relatively fewer, the value and range of soil erodibility index obtained in the experiments are close to that of the norm.

Soil erodibility index and its parameters: Table 3 shows the comparison between the Km values of each test area obtained from the experiment and the formula look-up table with the parameters such as the percentage of organic content (a), silty and fine sand content percentage (d) and the percentage of coarse sand content (e).

After analyzing the correlation between the parameters and the soil erodibility indexes, it was found that the Km in this study had a closer correlation with various factors than the formula look-up table does. The percentage of organic was highly related to the Km value, with a correlation coefficient of 0.512. However, in terms of the Km value of the formula look-up table, it is highly related to the silty and fine sand content percentage.

The experimental Km and normal Km of different areas: In Fig. 7, it can be learned that most of the experimental Km values in the north area are smaller than those of the normal ones, while the values in the rest areas varies without a regular pattern.

In terms of distribution, the experimental indexes of the central area are close to the normal range and the experimental Km ranges in the south and east area are larger than the normal range while the north smaller.

CONCLUSION

From the results, it can be concluded that the Southern areas of Taiwan are more susceptible to soil erosion. This is reflected by the large soil erosion index, that is, greater than 0.07. Also the lowest index (0.018) in these areas was larger than the other areas still indicating the lower resistance. In terms of soil texture, the country's texture showed large variability, which means low soil erosion resistance across the whole country. All land utilization types excluding landslides had wider variances, which would result to more variables affecting soil erosion resistance. The soil erosion index and its parameters analysis revealed that organic matter had a higher correlation with the soil erodibility index. In overall, the erodibility index in the north were smaller, central were closer to normal range and in the south and east were larger.

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