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Full Length Research Paper

Soil loss and erodibility factor for improving conservation specification design in Southwestern Taiwan

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The characteristics of the soil topography are usually influenced by the distribution of rainfall in typhoon season, steep terrains and fragmental geology; as a result, severe soil erosion often occurs in Taiwan. The aim of this study was to evaluate the relationship between the rainfall event and soil erodibility factor by collecting fifty nine measured erosion data from nineteen experimental sites among the six main rivers in the southwestern part of Taiwan. Three methods were employed to estimate the soil erosion factors; soil and water conservation design, soil test and regression with *in-situ* measurement of erosion. The test results showed that the soil erosion factors (SEFs) of Southwestern Rivers ranged from 0.015 to 0.03. The SEFs obtained using the soil tests were smaller than the SEFs from the soil and water conservation design specifications. For the SEFs of the five soil types (clay, silty loam, silty clay loam, very fine sandy loam and sandy), the result obtained from the test exhibits a wider range between 0.016 and 0.042. Moreover, from the investigation, it was found that the observed erosion was smaller than the one estimated by the USLE, which implied possible overestimation in using the equation.

Key words: Soil loss, erodibility factor, universal soil loss equation (USLE), rainfall conservation, Taiwan hillslope.

INTRODUCTION

In the mountainous area of southwestern Taiwan, rainfall is mainly accompanied by typhoons. Due to the effects of weak geological characteristics, steep slopes and gangue weathering; soil erodes significantly in these mountainous areas (Wang and Traore, 2009). Taiwan is an island covering 3.6 million hectares, 2.639 million of which are mountains and hills, accounting for 73.3% of the total area. As a result, hill slope development becomes inevitable. To effectively control the loss of soil and reduce soil erosion as development continues becomes a priority for soil and water conservation.

The universal soil loss equation (USLE) developed in the United States (US) is widely used for most soil erosion estimations as well as in many countries for soil loss estimates. The parameters used in this equation were representatives from two thirds of the eastern US. As time evolved, the accumulated data shaped the equation that is widely used in today's research work.

The soil loss estimation in the hill slope development of Taiwan is still based on the USLE. For the rainfall erosion index (R), Huang (1979) came up with the empirical equations unique to Taiwan. For other factors such as slope gradient, slope length, crop management and soil and water conservation processing (L, S, C, P), several studies were conducted to effect data correction. However, due to limited experiments, there is no appropriate estimation equation for local conditions of soil erosion factor (Km). The Km is a time-consuming process for *in-situ* measurement; hence it can only be estimated based on the basic property of soil.

Wann and Hwang (1989) adopted the monograph developed by Wischmeier et al. (1958) to collect soil

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samples from 280 sites around Taiwan for the estimation of soil erosion factors (SEFs), which are now included in the soil and water conservation, design manual for calculation of soil erosion. However, no specific coordinates were provided for these sampling sites and the data may not be sufficient, and thus the current collection of data still require further validation for practical application. Lin and Hung (2000) collected 5 soil samples in Miaoli using the block kriging skill, and created the isarithm maps of SEFs at Miaoli block and Jyhu block in Miaoli County. The limited number of sampling sites suggested that further validation may still be needed. Lin and Chang (2008) collected soil samples at 50 sites in Shimen reservoir upstream watershed for laboratory analysis. The comparison made possible by the USLE developed by Wischmeier et al. (1958), the SEF equation developed by the Soil Conservation Service (1978) and the empirical equation of Torri et al. (1997) revealed that the wider spectrum of factors included in the Wischmeier equation made it a potential equation for extended use. The studies of SEFs mentioned previously were all conducted to estimate the SEFs via lab analysis with soil samples taken on site. Due to the relative relationship between SEFs and rainfall, inaccurate SEFs may result if only soil properties are considered.

The study was designed specifically for six major rivers (Kaoping River, Laonong River, Ailiao River, Chishan River, Tungkang River and Linpien River) in the southwestern mountains of Taiwan. Undisturbed slopes were selected to install soil erosion measurement plots for *in-situ* measurement. Nineteen (19) plots were established for observation. Rainfall events were carefully documented to investigate the relationship between rainfall events and SEFs and the soil erosion characteristics of the southwestern mountains of Taiwan. The result will serve as the basis for the estimation of soil losses in soil and water conservation engineering.

MATERIALS AND METHODS

Study sites

The major rivers in the Southwestern Mountains of Taiwan were selected for *in-situ* erosion depth measurement. These rivers were Kaoping River, Laonong River, Ailiao River, Chishan River, Tungkang River and Linpien River. The nineteen (19) sites that were established and observed are shown in Figure 1.

Study method

Study flow

To achieve the goal of this study, the study flow shown in Figure 2 was employed. From the figure, one can find that there are six main works under plot set up. After the experimental plot was set, periodical measurement were carried out at least once a month for the calculations of soil erosion.

Test plots

Based on *in-situ* conditions, the plot size was 10 m long (up to downhill) and 2 m wide (lateral) as illustrated in Figure 3.

Erosion stake installation

Five (5) stakes were installed at every 2 m transect, that is, 1 stake/0.5 m; longitudinally, transects were selected at every 2.5 m and in total 5 were selected. Twenty five (25) stakes were installed in every plot. The erosion stake used was a round steel bar with 3/8” diameter and 30 cm long. A section of approximately 5 cm protruded above the ground and was painted in red (Figure 4).

Setup and measurement of test plots

For test plot setup, each of the stakes was driven into the soil using a custom-made sleeve, which was precisely machined to a depth of 25 cm. A caliper was used to measure the height from the ground to the top of stake as the first depth measurement. On the plot setup, the elevation was measured using a laser level. The elevation top of each stake was measured and documented as the visual height of the measurement spot, and the ground height was determined by subtracting the visual height with the measurement depth. The measurements were carried out at each of the twenty five stakes (A1, B1, C1, D1 and E1) and recorded (Figure 5). For the subsequent measurements, the ground height was determined by observing the protrusion of the stakes above the ground, and thus, the sediment depth of the spot was calculated. The soil hardness was measured and soil samples (5 kg) were taken around the test plots to conduct gravity test, color chart test, sieve analysis and organic carbon content test.

Estimation of SEFs

Determination using SEF nomographs

Two important findings were discovered in the nomograph analysis: The size of soil particles included very fine sand as well as silt, and the estimates of sand and silt improved. However, the determination of SEFs using nomographs was crude and inaccurate.

Determination using SEF equations

The equation developed by Wischmeier et al. (1958) was employed.

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

$$K = \frac{ton.acre.hr}{100.acre.feet.ton.in}$$

Where K: SEF in English units (times 0.137 to convert to SI unit, that is, Km = 0.1317k)
M: silt and very fine sand (0.002-0.1 mm) % x (100%-silt %)
a: organic material content % (taken as 4% even if it is greater than 4%)
b: soil structure index (Table 1)
c: soil infiltration index (Table 2)

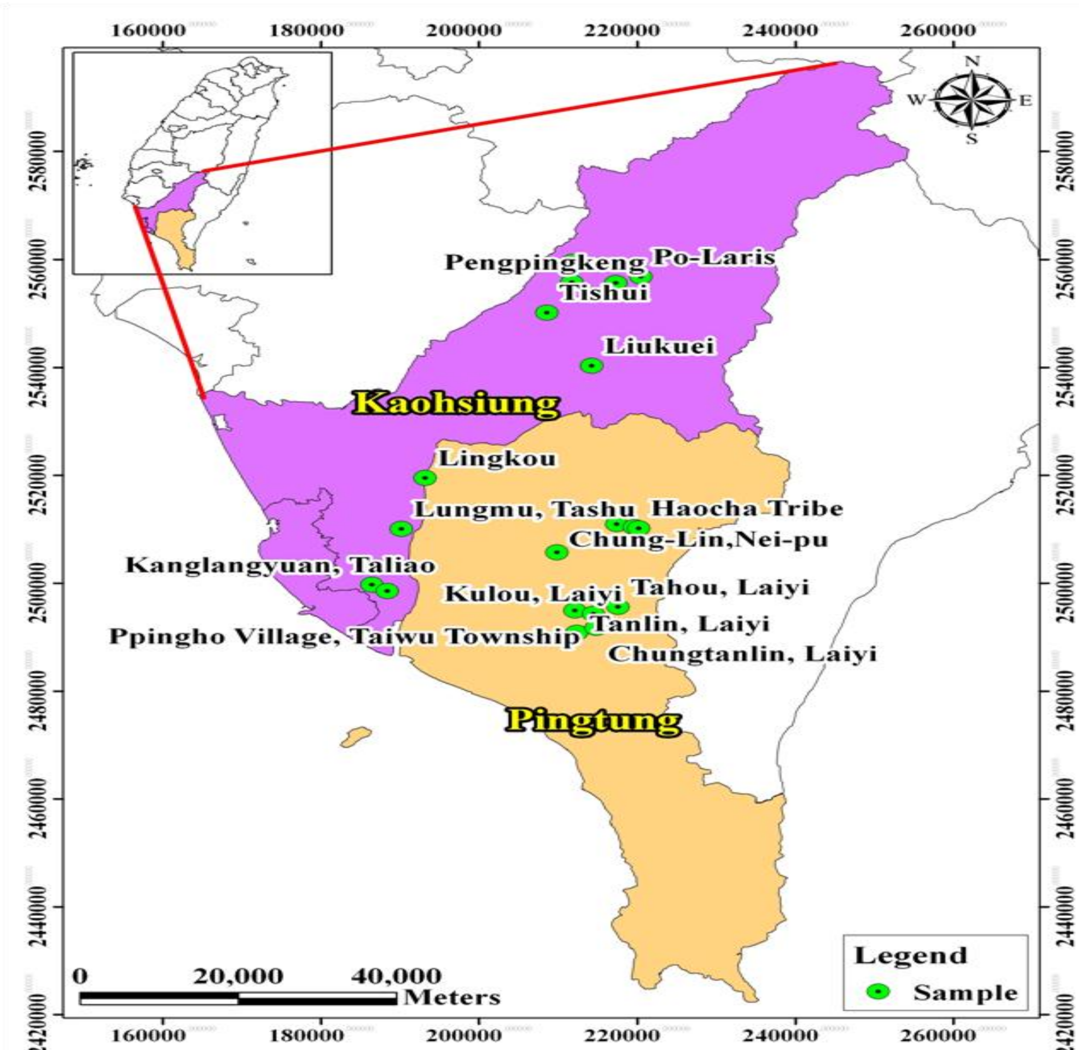

Figure 1. A map showing the distribution of the sampled sites.

Determination using SEF Table

Wann and Hwang (1989) adopted the nomographs of Wischmeier et al. (1958) to estimate the SEFs of soil samples collected from 280 sites around Taiwan and compiled the data into a table, from which the values were taken for calculation.

In-situ determination using approximate SEFs

The USDA-SCS developed the SEF table shown in Table 3 in 1978 for the convenience of soil and water conservation engineers to determine the SEFs. This table is practical only for *in-situ* soil properties and yields the approximate value of SEFs.

RESULTS AND DISCUSSION

The basic soil properties and SEFs of each site in this study were analyzed to find out the related site distribution and SEF values which are shown in Table 4.

The SEFs of the southwestern river systems

Table 5 shows the SEFs (Km) of the representative sites of each river system. Figure 6 and Table 6 show the range of SEFs distribution. Geostatistics was used to convert the data obtained into the isarithm maps of SEFs in southwestern Taiwan, as shown in Figure 7. The test result showed that the SEFs of southwestern rivers ranged from 0.015 to 0.03. The SEFs determined using the soil and water conservation design specifications ranged from 0.015 to 0.042 and were larger when compared to the SEFs from the soil tests. For the overall relative magnitude of SEFs, the values from tests and those from design specification displayed a somewhat consistent relationship in relative magnitude for different river systems.

The SEFs of Laonong River and Chishan River were higher, while that of Ailiao River was smaller. This means the Laonong and Chishan Rivers were less resistance to

Figure 2. A flowchart showing the study flow.

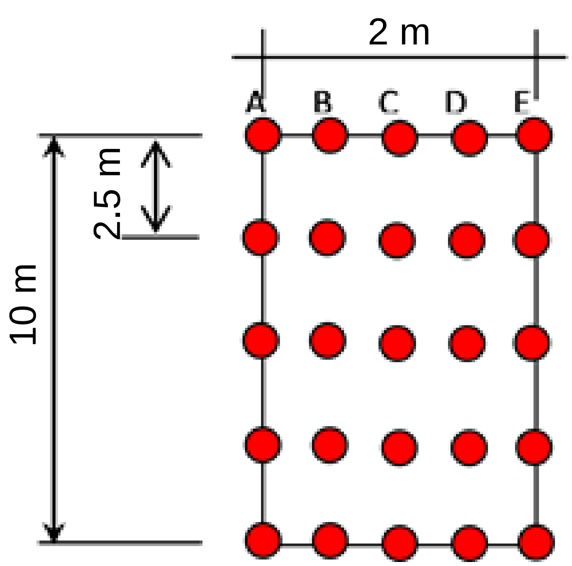

Figure 3. The layout of a typical test plot.

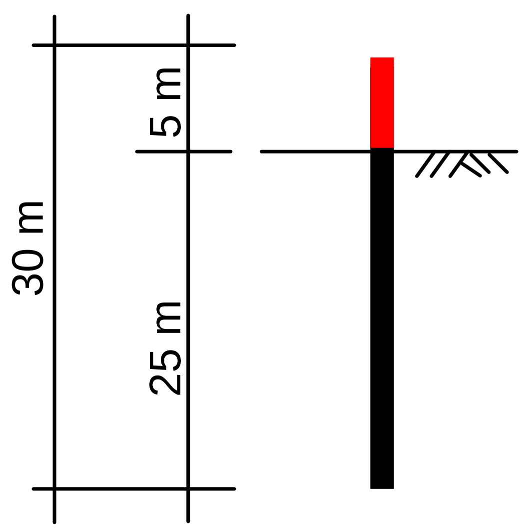

Figure 4. Erosion stake.

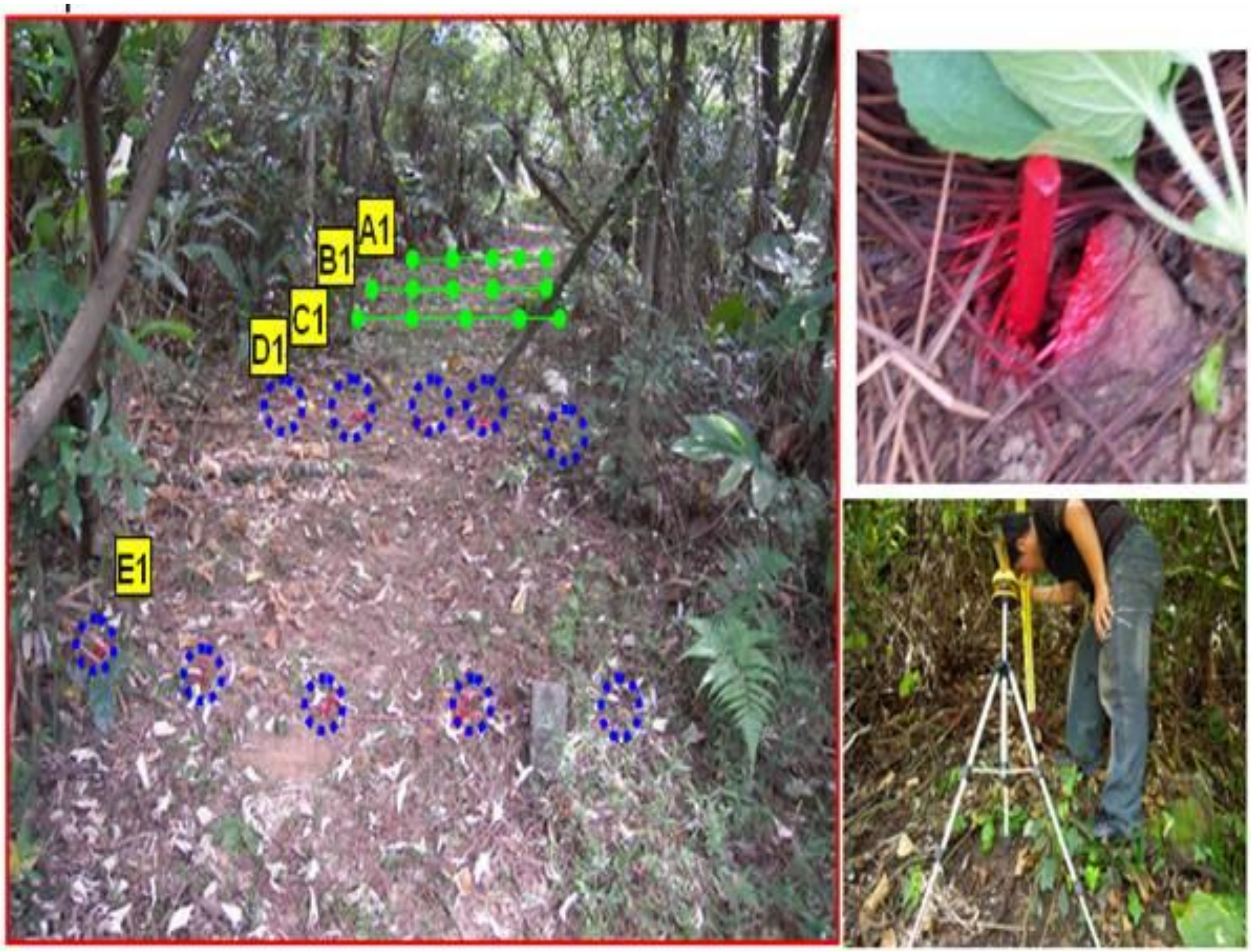

Figure 5. Pictures showing a test plot setup.

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/hr)
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

Table 3. Approximate SEFs of typical topsoil.

Topsoil Property	Km (SI)
Clay, clay loam, loam, silty clay	0.042
Fine sandy loam, very fine sandy loam, sandy loam	0.032
Loamy fine sand, loamy sand	0.022
Sand	0.020
Silty loam, silty clay loam, very fine sandy loam	0.049

Source: Soil Conservation Service (1978).

Table 4. Basic information of sample sites.

Site	County/City	X	Y	Soil Texture	Specification Km	River
Chunglin, Neipu	Pingtung	209844	2505670	SL	0.029	Tungkang
Hoping Village,	Pingtung	212160	2494873	SL	◎	Tungkang
Tanlin, Laiyi	Pingtung	212386	2490754	SL	0.0224	Linpien
Kulou, Laiyi	Pingtung	214507	2494274	SL	0.0303	Linpien
Laiyi	Pingtung	214814	2491636	※		Linpien
Tahou, Laiyi	Pingtung	217606	2495529	SL	◎	Linpien
Taliao	Kaohsiung	186471	2499627	SiCL	0.0158	Kaoping
Taitienfu	Kaohsiung	188382	2498510	SL	0.025	Kaoping
Lungmu, Tashu	Kaohsiung	190175	2509970	SiL	0.0408	Kaoping
Lingkou	Kaohsiung	193186	2519446	SiL	0.025	Kaoping
Liukuei	Kaohsiung	214267	2540251	S	0.0408	Laonong
Chienshan	Kaohsiung	217321	2555610	SM	◎	Laonong
Paolai	Kaohsiung	220466	2556755	SL	◎	Laonong
Ailiaonan	Kaohsiung	217413	2510874	L	0.0171	Ailiao
Haocha 2 Bridge	Kaohsiung	219680	2510329	SL	◎	Ailiao
Haocha Tribe	Kaohsiung	220202	2510125	SL	◎	Ailiao River
Tishui	Kaohsiung	208567	2550122	SiCL	0.0421	Chishan River
Pengpingkeng	Kaohsiung	211781	2555735	SiL	◎	Chishan River
Hsiaopeishihkeng	Kaohsiung	211789	2559510	SiCL	0.0329	Chishan

※, The site is damaged beyond measurement; ◎, no available data at the vicinity of any site in the specifications; SL, sandy loam; SiCL, silty clay loam; SiL, silty loam; S, sand; L, loam.

soil erosion when compared to Ailiao River.

Different southwestern soil properties and the range of SEFs

By categorizing the SEFs based on different soil texture, the results obtained are shown in Figure 8. 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 SEFs (Km). However, the test results showed that by comparing the SEFs of sand and loam taken from southwestern Taiwan, the SEFs of sand were greater than those of loam. For other soil textures, they fit the general trait of SEFs, that is, the coarser the texture, the smaller the SEFs. The test result of the SEFs of the southwestern soil was compared with the SEF table developed by USDA-SCS in 1978, and the results are shown in Table 7. Apart from the reverse trait of clay and sand, the traits of other soil textures were roughly consistent; for the SEFs of the five types of soil, the result obtained from this test exhibits a wider range between 0.016 and 0.042, whereas the same SEF had a single value of 0.049 in the USDA-SCS table.

The southwestern SEFs and their relationship with other parameters

Table 8 shows the Km obtained from the test plots of Southwestern Taiwan and that obtained from SEF table versus organic material content in soil (a), silt and very

Table 5. SEFs of the representative site of each river.

Name	X	Y	Experimental Km	Specification Km	River
Chunglin, Neipu	209844	2505670	0.0258	0.0290	Tungkang
Hoping Village,	212160	2494873	0.0148	◎	Tungkang
Tanlin, Laiyi	212386	2490754	0.0295	0.0224	Linpien
Kulou, Laiyi	214507	2494274	0.0193	0.0303	Linpien
Laiyi	214814	2491636	※		Linpien
Tahou, Laiyi	217606	2495529	0.0218	◎	Linpien
Taliao	186471	2499627	0.0170	0.0158	Kaoping
Taitienfu,	188382	2498510	0.0191	0.0250	Kaoping
Lungmu, Tashu	190175	2509970	0.0213	0.0408	Kaoping
Lingkou	193186	2519446	0.0206	0.0250	Kaoping
Liukuei	214267	2540251	0.0252	0.0408	Laonong
Chienshan	217321	2555610	0.0301	◎	Laonong
Paolai	220466	2556755	0.0298	◎	Laonong
Ailiaonan	217413	2510874	0.0147	0.0171	Ailiao
Haocha 2 Bridge	219680	2510329	0.0191	◎	Ailiao
Haocha Tribe	220202	2510125	0.0237	◎	Ailiao
Tishui	208567	2550122	0.0255	0.0421	Chishan
Pengpingkeng	211781	2555735	0.0257	◎	Chishan
Hsiaopeishihkeng	211789	2559510	0.0236	0.0329	Chishan

※, The site is damaged beyond measurement; ◎, no available data at the vicinity of any site in the specifications.

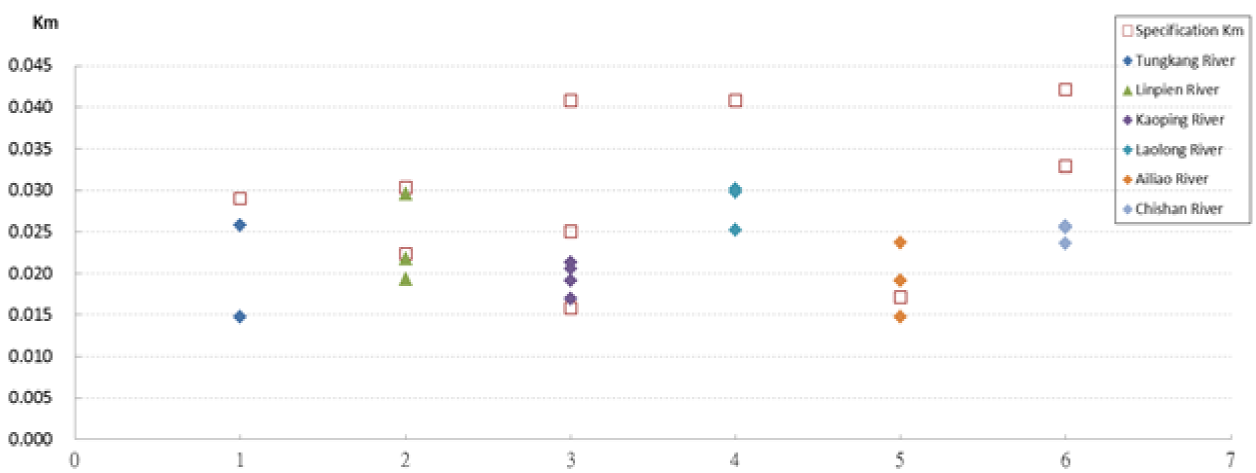

Figure 6. The distribution of SEFs along the Southwestern River systems.

Table 6. Approximate SEFs of the Southwestern River systems.

Item	River	Specification Km	Experimental Km
1	Tungkang River	0.029	0.015~0.026
2	Linpien River	0.022~0.03	0.019~0.03
3	Kaoping River	0.016~0.041	0.017~0.021
4	Laonong River	0.041	0.025~0.03
5	Ailiao River	0.017	0.015~0.024
6	Chishan River	0.033~0.042	0.024~0.026

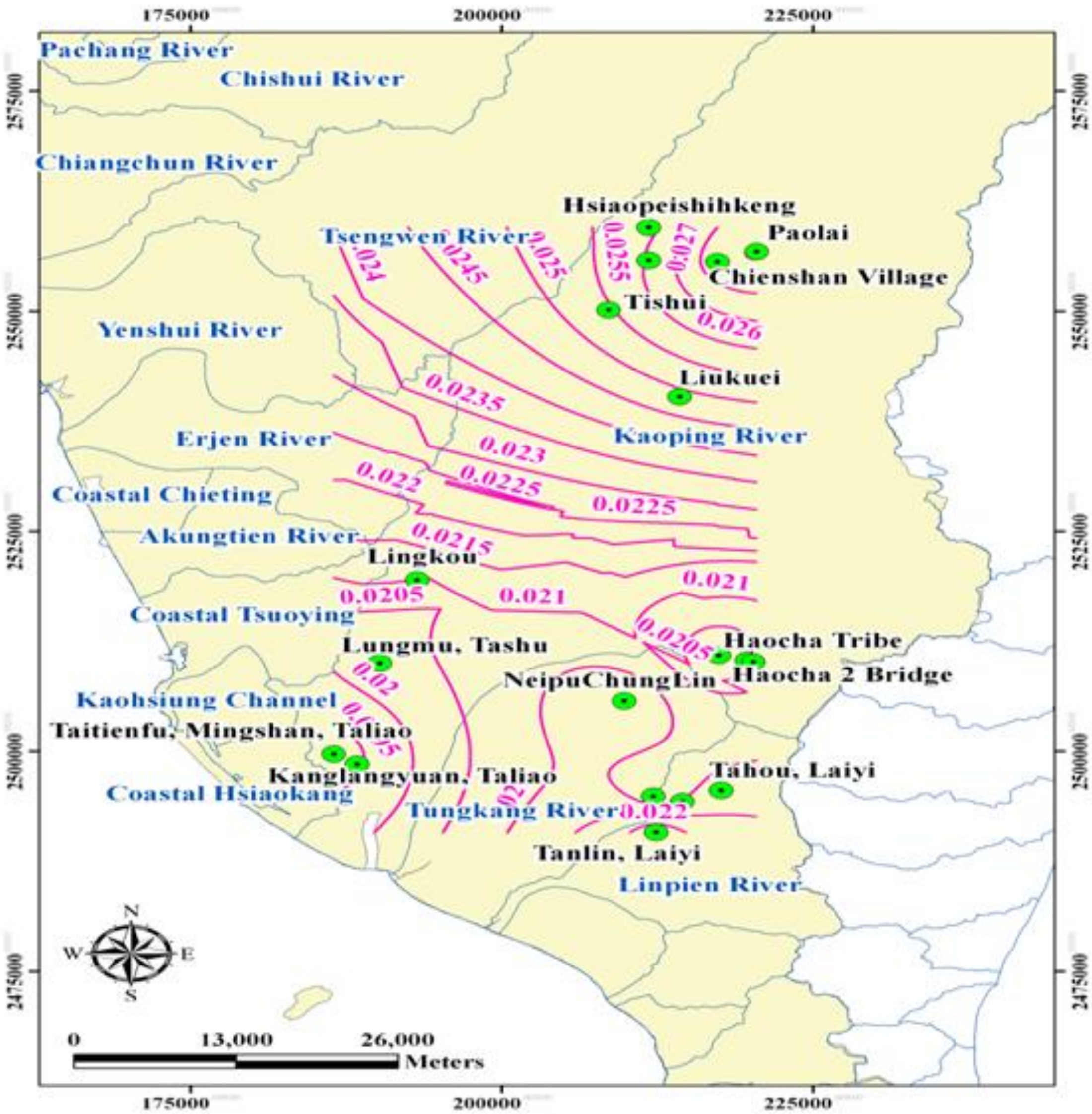

Figure 7. Isarithm map showing SEFs of the Southwestern River systems.

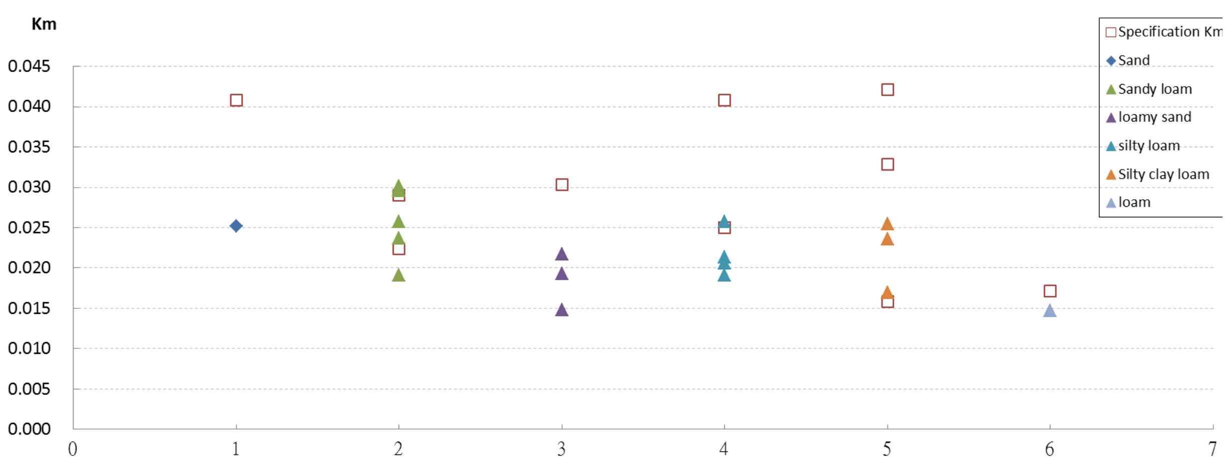

Figure 8. The distribution of SEFs from soil samples taken along Southwestern Taiwan with various textures.

Table 7. Approximate SEFs of typical soil textures in Southwestern Taiwan.

Type	Topsoil Texture	USDA Km	Southwestern Taiwan Km
1	Clay, clay loam, loam, silty clay	0.042	0.017
2	Fine sandy loam, very fine sandy loam, sandy loam	0.032	0.019~0.030
3	Loamy fine sand, loamy sand	0.022	0.015~0.022
4	Sand	0.02	0.04
5	Silty loam, silty clay loam, very fine sandy loam	0.049	0.016~0.042

Table 8. SEFs versus factors having influence on SEFs.

Site	Km	Specification Km	Rm	a	b	c	0.002~0.1(d)	0.1~2(e)
Chunglin, Neipu	0.0258	0.0290	18909	4.36	3	4	61.43	14.99
Hoping Village,	0.0148	◎	44712	5.18	3	3	49.73	12.89
Tanlin, Laiyi	0.0295	0.0224	21854	3.82	3	3	70.69	14.13
Kulou, Laiyi	0.0193	0.0303	21854	7.49	4	4	51.02	14.07
Tahou, Laiyi	0.0218	◎	21854	4.83	4	5	42.32	3.79
Taliao	0.0191	0.0250	13650	4.58	3	3	47.97	33.33
Taitienfu,	0.0191	0.0250	13650	4.58	3	3	47.97	33.33
Lungmu, Tashu	0.0213	0.0408	20000	4.63	2	3	59.01	34.92
Lingkou	0.0206	0.0250	25000	5.75	3	4	44.80	44.65
Liukuei	0.0252	0.0408	20000	5.58	4	4	62.41	4.41
Chienshan	0.0301	◎	25000	4.91	3	4	71.18	15.43
Paolai	0.0298	◎	20000	2.13	4	3	62.81	5.66
Ailiaonan	0.0147	0.0171	24556	6.78	3	5	29.21	23.37
Haocha 2 Bridge	0.0191	◎	24556	4.95	4	4	44.53	4.07
Haocha Tribe	0.0237	◎	24556	2.03	4	5	37.86	9.66
Tishui	0.0255	0.0421	25000	5.26	3	4	63.66	17.76
Pengpingkeng	0.0257	◎	21028	3.14	3	5	58.36	0.42
Hsiaopeishihkeng	0.0236	0.0329	21028	3.66	3	3	65.56	4.80

◎, No available data at the vicinity of any site in the specifications.

fine sand content percentage (d) and coarse sand percentage (e).

Figure 9 shows the correlation result from the analysis of the individual influence factors and SEFs. The results showed that the test conducted on soil samples from Southwestern Taiwan, that is, the silt and very fine sand content (d) had a higher correlation with SEF. In general, the relationship between the Km obtained from the test and the factors was more significant than that between Km from SEF table and the factors.

SEFs of southwestern soil and their relationship with rainfall

Eleven (11) representative plots were selected in the Northern, Central and Southwestern parts of Taiwan for this assessment. The table in the soil and water conservation design specification (Method 1), soil test (Method 2) and regression with *in-situ* measurement of erosion (Method 3) were employed to obtain SEFs. The cumulated rainfall from April to July 2010 was collected for comparison as shown in Table 9.

In general, the SEFs have higher correlation with soil texture and parent rock, and rainfall is susceptible to rainfall erodibility index (Rm). However, the relationship between SEFs obtained in different methods and the cumulated rainfall, as shown in Figures 10 to 12, suggests that the SEFs obtained from Method 1 had a greater correlation with the cumulated rainfall, followed by Method 2 and 3.

Conclusion

The results show that the SEFs of southwestern rivers ranged from 0.015 to 0.03, with the highest SEF from Laonong River. The high SEF indicates less resistance to

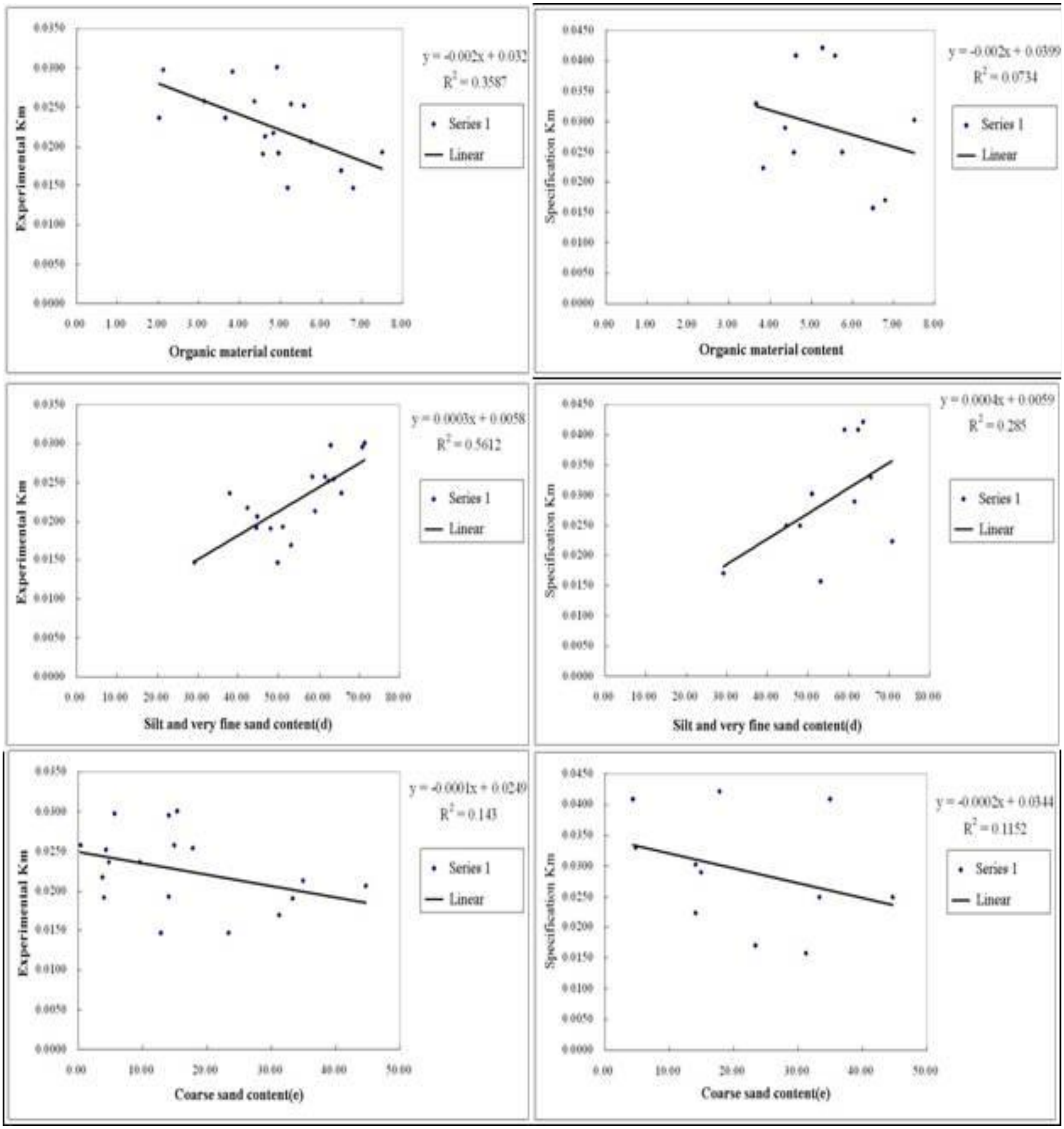

Figure 9. Km estimated using different methods versus various SEFs.

soil erosion when compared to those rivers with low SEFs. The SEFs obtained using the soil tests were smaller than the SEFs from the soil and water conservation design specification. The test results show that the SEFs of sand and loam taken from southwestern Taiwan fit the general trait of SEFs, that is, the coarser

Table 9. Km obtained using various estimate methods versus cumulated rainfall.

County	Plot	Km from table (Method 1)	Km from soil test (Method 2)	Km calculated from stake measurements (Method 3)	Cumulated rainfall from Apr to Jul 2010 (mm)
Taoyuan	Luofu	0.0171	0.0276	0.0007	632
Taoyuan	Pingting	0.0237	0.0362	0.0036	527.5
Nantou	Wuayao Landslide	0.0474	0.0185	0.012	1013
Nantou	Tsukeng Bridge	0.0474	0.0194	0.0028	939.5
Kaohsiung	Tishui	0.0421	0.17	0.0872	1587
Kaohsiung	Hsiaopeishihkeng	0.0329	0.0206	0.0431	1547
Pingtung	Tanlin, Laiyi	0.0224	0.0147	0.0028	998
Pingtung	Hoping Village, Taiwu Township	0.0303	0.017	0.0052	998
Taipei	Shihting	0.0408	0.0316	0.0091	668
Taipei	Linkou	0.0237	0.0377	0.0046	527.5
Yilan	Sungluo	0.0132	0.0258	0.0081	849

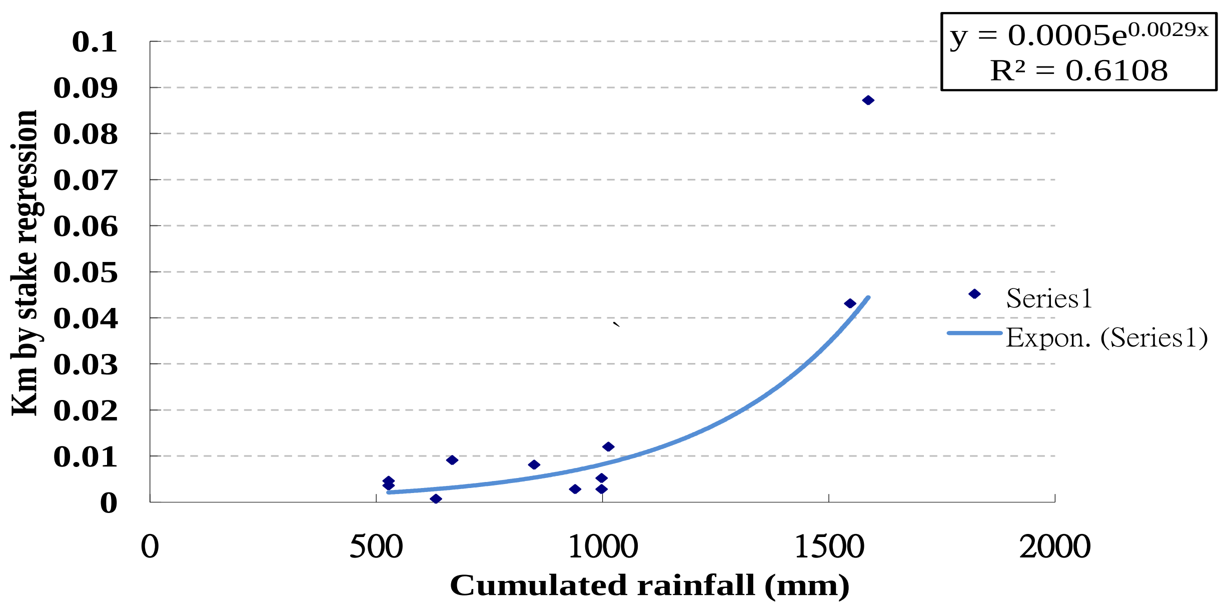

Figure 10. Km obtained from regression with *in-situ* measurement of erosion versus cumulated rainfall.

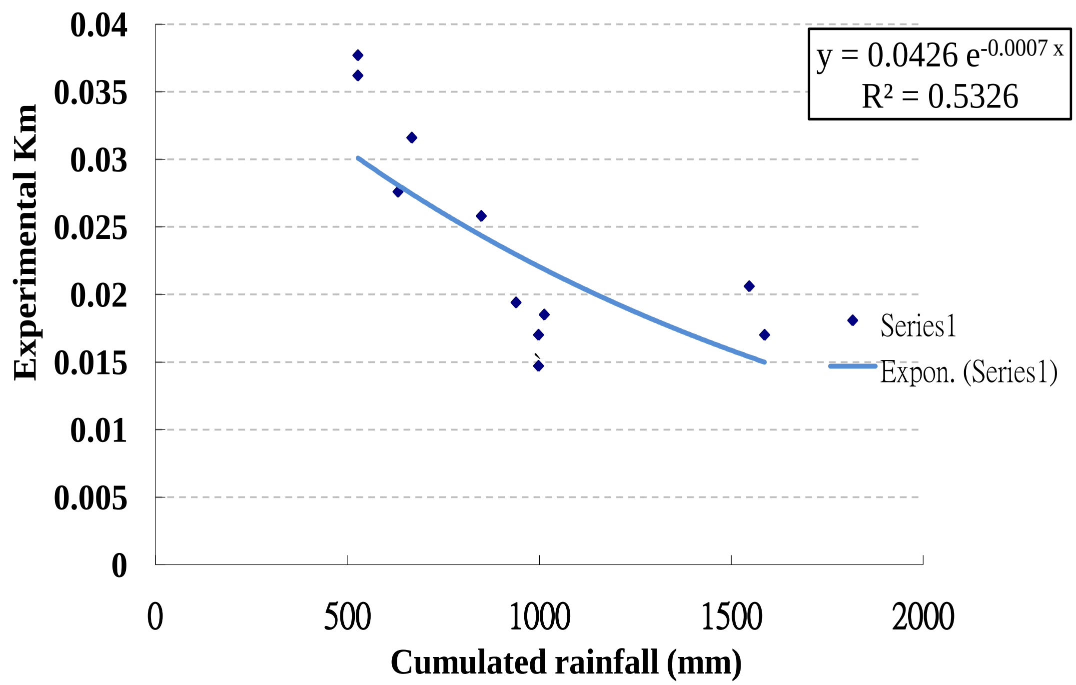

Figure 11. Km obtained from soil test versus cumulated rainfall.

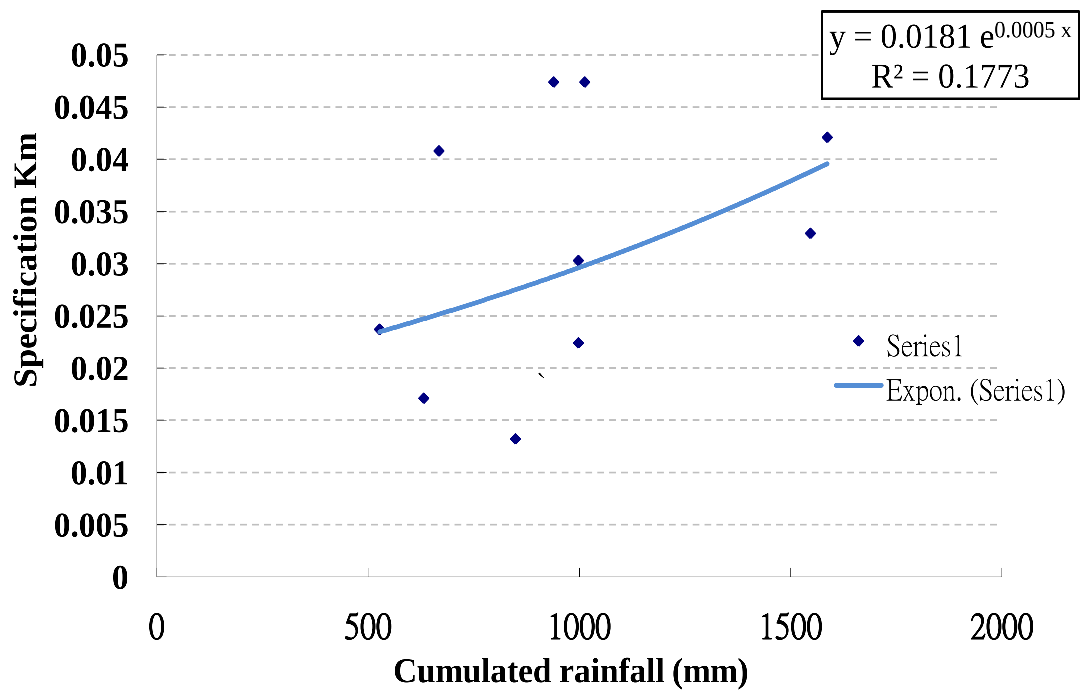

Figure 12. Km obtained from SEFs table in the design specification versus cumulated rainfall.

the texture, the smaller the SEFs. This is so, because the SEFs for sand were found to be greater than SEFs for loam. The test result of the SEFs of the southwestern soil was compared with the SEF table developed by USDA-SCS in 1978. Apart from the reverse trait of clay and sand, the traits of other soil textures were consistent; for the SEF of the 5 types of soil (clay, silty loam, silty clay loam, very fine sandy loam and sand), the result obtained from this test exhibits a wider range from 0.016 to 0.042. The relationship between the SEFs obtained from various methods and the cumulated rainfall suggests that the correlation between the SEFs estimated using regression with *in-situ* measurement of erosion and the cumulated rainfall was the greatest. However, correlation between SEFs obtained using the SEF table in the soil and water conservation design specification and the rainfall was the lowest. The SEFs estimated using the soil test results and the cumulated rainfall are somewhat correlated, and the SEFs decreased with the cumulated rainfall instead of increasing.

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