ERODIBILITY FACTOR OF LOCAL MADRID SOILS

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SUMMARY. This article reports on a study to determine the erodibility factor for the following Madrid soil types known locally as "arena de miga", "tosco" and "peñuela" as a means of applying the Universal Soil Loss Equation (USLE) to ascertain predictable soil loss in the slope cuts resulting from excavations for roads and other communication ways.

Measurements were taken of the actual erosion occurring in slopes on a road surrounding Madrid that cut through these three soil types and the calculated and field-measured soil loss values obtained were analysed.

1. INTRODUCTION

The Universal Soil Loss Equation (USLE) proposed by Wischmeier & Smith (1965) was used to predict the soil loss that could occur in slopes as a result of laminar or rill-type erosion caused by rainwater.

The USLE incorporating the modification by Israelsen et al (1980) is as follows:

$$A = R.K.L.S.VM$$

where:

A = annual soil loss in t/ha
R = rain erosion index
K = soil erodibility factor
L = slope length dependent factor

S = slope angle function factor

VM = erosion protection function factor

The R index introduces the rain aggression factor into the USLE, quantified by the kinetic energy of each rainstorm. The R values represent the sum of kinetic energies of the rainstorms occurring over one year. These values were published by ICONA in 1988 in the so-called "Rain Aggression Map for Spain" (Fig. 1).

The K factor represents the soil characteristics constituting the slope surface, expressed as:

$100 \cdot K = 10^{-4} \cdot 2.1 \cdot M^{1.14} \cdot 12- a)+4.20 \cdot (b-2)+3.23 \cdot (c-3)$

where:

M: particle size function parameter, the product of multiplying the percentage of soil particles of between 0.002 and 0.1 mm in diameter by the percentage of soil particles of between 0.002 and 2.0 mm in diameter

a: percentage of organic matter

b: soil structure function parameter according to the values:

1 = very fine grain and lump size (< 1 mm)

2 = fine grain and lump size(1-2 mm)

3 = medium grain and lump size (2-5 mm) and coarse grain (5-10 mm)

4 = smooth, columnar prismatic and very coarse grain (> 10 mm)

c: profile permeability class (USDA Soil Survey Manual):

1 = fast to very fast

2 = medium fast

3 = moderate

4 = moderately slow

5 = slow

6 = very slow.

It takes into account the following parameters: soil grading, specifically the particles under 2 mm, distinguishing between those under 2 mm and those under 0.1 mm, organic matter content, type of soil particle and permeability.

Slope length and angle are introduced into the USLE by a factor grouping the two parameters (LS) and which in the case of angles over 20%, which are typical of cut slopes, the expression is:

$$LS = \left(\frac{\lambda}{22,1}\right)^{0,3} \left(\frac{S}{9}\right)^{1,3}$$

where:

λ=slope length in m

S =slope angle, in %.

The VM factor represents the degree of protection from erosion possible in the soil. Israelsen et al (1980) propose different values, from VM=1, for recently scarified soil to a depth of 15 to 20 cm, to VM=0.01 for soils or soil surfaces covered by vegetation.

2. ERODIBILITY FACTOR OF MADRID SOILS

In road slopes, and specifically in the slopes studied on Madrid's M-40 Beltway, the content of organic matter tends to be low, generally less than 0.22%, whereby a value for K of a=0 was calculated for all of them.

Also taken for all the Madrid soils covered in this study was a fine grain and lump soil structure representing a value of b=2, plus a moderate slope permeability with a value of c=3.

In these conditions, the K erodibility factor is reduced to the first section of the above equation:

$$100K = 10^{-4} \cdot 2.1 \cdot M^{1.14} \cdot 12$$

$$100K = 10^{-4} \cdot 25.2 \cdot M^{1.14}$$

Based on these general properties for the tosco, arena de miga and peñuela soil types, the values for K taken from Escario (1985) were calculated for the three types, as shown in Table 1.

The following average values can be taken as representative of these three soil types:

tosco: k = 0.160
sandy tosco: K = 0.169
arena de miga: K = 0.067
peñuela: K = 0.39

Even though a distinction was drawn between tosco and sandy tosco, there is virtually no change in the value of the K erodibility factor in the two.

Arena de miga had the lowest erodibility index, K=0.067. For tosco it was K=0.160, which is 2.4 times higher than for arena de miga, and the peñuela index was K=0.39, which is 5.8 times higher than the arena de miga sand.

3. EROSION MEASUREMENTS IN CUT EMBANKMENTS IN MADRID SOILS

Three types of erosion pattern were distinguished for measuring the erosion in the slopes: rill, runnel and gully, depending on the depth of erosion existing - rills down to a depth of 15 cm, runnels down from 15 to 30 cm and gullies over 30 cm in depth.

The section that could be considered average for the slope length was measured in each of them and the frequency in which erosion appeared per metre of slope length was determined.

Table 2 gives these data for the particular slopes analysed. Runnels and gullies appeared in slope No. 3 and the two types of erosion were determined separately.

Based on these data, the volume of eroded soil per square metre of surface area could be determined as also for the time that had transpired from when the excavation was executed. The particular slopes studied here had been exposed for five years.

The weight of eroded soil was obtained from the volume, multiplied by the density, in this case taken to be 2000 kg/m^3.

Slopes T-9, T-11 and T-12 were covered with profuse vegetation and did not expose any type of erosion. If it ever did exist at the start, it must have been of the laminar type.

4. CALCULATION OF SOIL LOSS ON CUT SLOPES IN MADRID SOILS

The K erodibility factor was calculated from samples obtained directly from the surface of the slopes in eight cuts on the M 40 Expressway (Table 3) and the soil loss was also calculated using the US-LE, (A end column, Table 3), taking into account the LS factor covering slope length and angle.

4.1. Behaviour of Slopes Cut in Arena de Miga Soil

The K erodibility factor for the arena de miga soil in the slopes studied ranged from K=0.062 to K=0.096, meaning K=0.077 could be taken as average value.

A slope on arena de miga with an angle of 40° and height of 16 m (LS=16.55) in the Madrid environment (R=75), and an erosion control factor of VM=1, which corresponds to soil without any vegetation and that is loose and smooth, would experience the following soil loss, calculated by the USLE method:

$A = k \cdot LS \cdot R = 0.077 \cdot 16.55 \cdot 75 = 95.6$ ton/ha per year $A = 9.56$ kg/m^2 per year.

The soil loss values calculated by the USLE method for each slope on arena de miga studied here ranged from A_i=4.5 kg/m^2 per year to A_s=13.5 kg/m^2 per year, depending essentially on the slope height involved.

The soil loss values obtained by field measure-ments ranged from A_{ci}=0.3 kg/m^2 per year for Slope T-5 to A_{ci}=2.3 kg/m^2 per year for Slope T-3.

The effect of vegetation on the actual erosion suffered by the slopes was relatively obvious. Taking Slopes T-1 and T-5 located on the two sides of the M-40 Beltway, the fact that T-5 was densely covered by vegetation meant its soil loss was 0.3 kg/m^2 per year as against the 11.5 kg/m^2 per year loss calculated for Slope T-1.

The highest erosion loss values were detected in Slopes T-3 and T-4, which were the highest slopes we studied. Slope T-4 with its plentiful vegetation registered a soil loss of 14.4 kg/m^2 per year as compared to the 25.3 kg/m^2 per year lost in Slope T-3.

This same T-3 showed a large discrepancy between the values calculated by the USLE and the value obtained in the field measurement. The difference lay in the LS factor of 12.57, as compared to an LS=19.79 in Slope T-4. This difference in values was put down to the different slope angles involved. Slope T-3 has a more extended slope than T-4 which, in the USLE calculation mitigates the erosion. However, the field measurements made did not reflect this reduction in the actual circumstances.

4.2. Behaviour of Slopes Cut in Tosco Soil

The two slopes cut in tosco that were studied here were T-7 and T-9, both corresponding to the same cut operation.

The K soil erodibility factor values obtained in the slopes cut in tosco were K=0.176, K=0.037 and K=0.127. Their average worked out at K=0.113.

Taking into account the characteristic grading for Madrid tosco, the average value for the erodibility factor was K=0.160, which is above the average value obtained in the slopes analysed.

The soil loss calculated by the USLE for the sandy tosco slopes studied could be taken as A=1.9

kg/m^2 per year.

The soil losses obtained from field measurements were A=4.2 kg/m^2 per year in Slope T-7 which has a low level of vegetation, and a virtually non-existent soil loss in T-9 which is covered by plentiful vegetation.

4.3. Behaviour of Slopes Cut in Peñuela Soil

Two slopes on peñuela soil were studied, T-11 and T-12, situated on the two sides of the expressway at km point 18.7. The grading analysis data obtained in the two samples taken did not match as different values were obtained for the erodibility factor.

In the peñuela type of soil the following characteristic average values can be taken for the different grading sizes: 98% passing a standard 0.08 UNE screen; 30% of particles of less than 0.002 UNE; 100% of particles of less than 2 UNE. A high erodibility factor could be deduced from these values of K=0.39. This is similar to the value field measured in Slope T-12.

The soil loss calculated for the same T-12 slope by applying the USLE was A=27.9 kg/m^2 per year, which proved to be the highest value calculated.

These two slopes were covered with plentiful vegetation and no significant erosion was observed in them.

5. CONCLUSIONS ON EROSION IN SLOPES BUILT UP ON MADRID SOILS

Slopes on Arena de Miga Soil

The erodibility factor for arena de miga soil in the Madrid area has an average value of K=0.067.

The soil loss to be predicted for an average slope cut from local Madrid arena de miga soil (height of h=16 m, angle of α=40°) without any vegetation cover will be:

$$A = 9.56 \text{ kg/m}^2 \text{ per year.}$$

Slopes on Tosco Soil

The erodibility factor for tosco soil in the Madrid area has an average value of K=0.160.

The average value for the erodibility factor in the slopes tested built on tosco was K=0.113.

Soil loss in tosco soil calculated using the USLE was A=1.9 kg/m^2 per year for the slopes analysed in this particular study.

Soil loss measured in situ on the slopes was A=4.3 kg/m^2 per year, higher than the calculated value.

Slopes in Peñuela Soil

The erodibility factor for peñuela soil in the Madrid area has an average value of K=0.39.

Soil loss in the slopes on peñuela calculated using the USLE was A=27.5 kg/m^2 per year.

The two slopes were covered with plentiful vegetation and no significant erosion was observed in them.

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Figure 2. Rill erosion in Slope T-1

Figure 3. Rill erosion in Slope T-7

Fig. 2. Regueros en el talud T-1

Fig. 3. Regueros en el talud T-7

Table 1. Erodibility Factor K in Local Madrid Soils. (Based Only on Particle Size)

	% Passing a UNE 2 Screen	% Passing a UNE 0.1 Sc.	% Passing a UNE 0.002 Sc.	A 0.1-0.002	B 2-0.002	M	$M^{1,14}$	25.2 $M^{1,14}$	K
				TOSCO					
Max.	100	66	23	43	57	2451	7309	184187	0.184
Min.	100	30	9	21	79	1659	4684	118039	0.118
Ave.	100	48	16	32	68	2676	6382	160817	0.160
				SANDY TOSCO					
Max.	100	94	51	43	57	2451	7309	184187	0.184
Min.	92	66	23	43	49	2107	6151	555017	0.155
Ave.	96	80	37	43	53	2279	6727	169520	0.169
				ARENA DE MIGA					
Max.	92	30	8	22	84	1848	5287	333232	0.133
Min.	74	6	2	4	72	288	636	16027	0.016
Ave.	83	18	5	13	78	1014	2672	67334	0.067
				PEÑUELA					
Ave.	100	98	30	68	70	4760	15576	392539	0.39

Table 2. Erosion Measurements Taken in Slopes Cut in Local Madrid Soils

Slope	Soil Type	Erosion Type	Section m^2	Frequency Reg/m	Soil Erosion m^3/m^2 (1)	T m^3/m^2 year	Erosion kg/m^3 year	
1	Arena miga	Rill	0.018	1.6	0.0288	0.00576	11.52	Fig.2
3	Arena miga	Runnel	0.0264	1.5	0.0396	0.00792	25.34	
3	Arena miga	Gully	0.475	0.05	0.02375	0.00475	25.34	-
4	Arena miga	Runnel	0.018	2	0.036	0.0072	14.42	-
5	Arena miga	Rill	0.001	0.8	0.0008	0.00016	0.32	-
7	Tosco	Rill	0.004	2.6	0.0104	0.00208	4.16	Fig.3
9	Tosco	-	-	-	-	-	-	-
11	Peñuela	-	-	-	-	-	-	-
12	Peñuela	-	-	-	-	-	-	-

(1) Erosion produced in the five years since the slope was executed.

Table 3. Erodibility Factor K and Soil Loss in Slopes on the M-40 Expressway in Madrid

	pK	h (m)	α	Direc-tion	Soil	Vegetation	Soil Loss (1) kg/m^2 year	K	LS	R (2)	A kg/m2 year(3)
T-1	57	16	40°	S		Low	11.5	0.062	16.55	75	7.7
T-3	-	19	35°	S	Arena miga	Low	25.3	0.062	9.57	75	4.5
T-4	-	29	35°	N	Arena miga	Dense	14.4	0.091	19.79	75	13.5
T-5	56	11	40°	N	Arena miga	Dense	0.3	0.096	14.79	75	10.6
T-7	11.3	9.8	40°	E	Arena miga	Low	4.2	0.037	11.6	75	3.2
-	-	-	-	-	Tosco	-		0.176	14.29	-	1.9
T-9	12.3	13	45°	NE	-	Plentiful	-	0.127	19.51	75	1.9
T-11	18.7	11	35°	E	Tosco	Plentiful	-	0.081	11.67	75	7.1
T-12	18.7	11	30°	W	Peñuela	Plentiful	-	0.41	16.77	75	27.9
					Peñuela						

(1) A_c soil loss measured in situ on slope surface

(2) The R values were obtained from the 1:1,000,000 scale "Rain Aggression Map for Spain" published by ICONA (1988)

(3) A = soil loss calculated using th

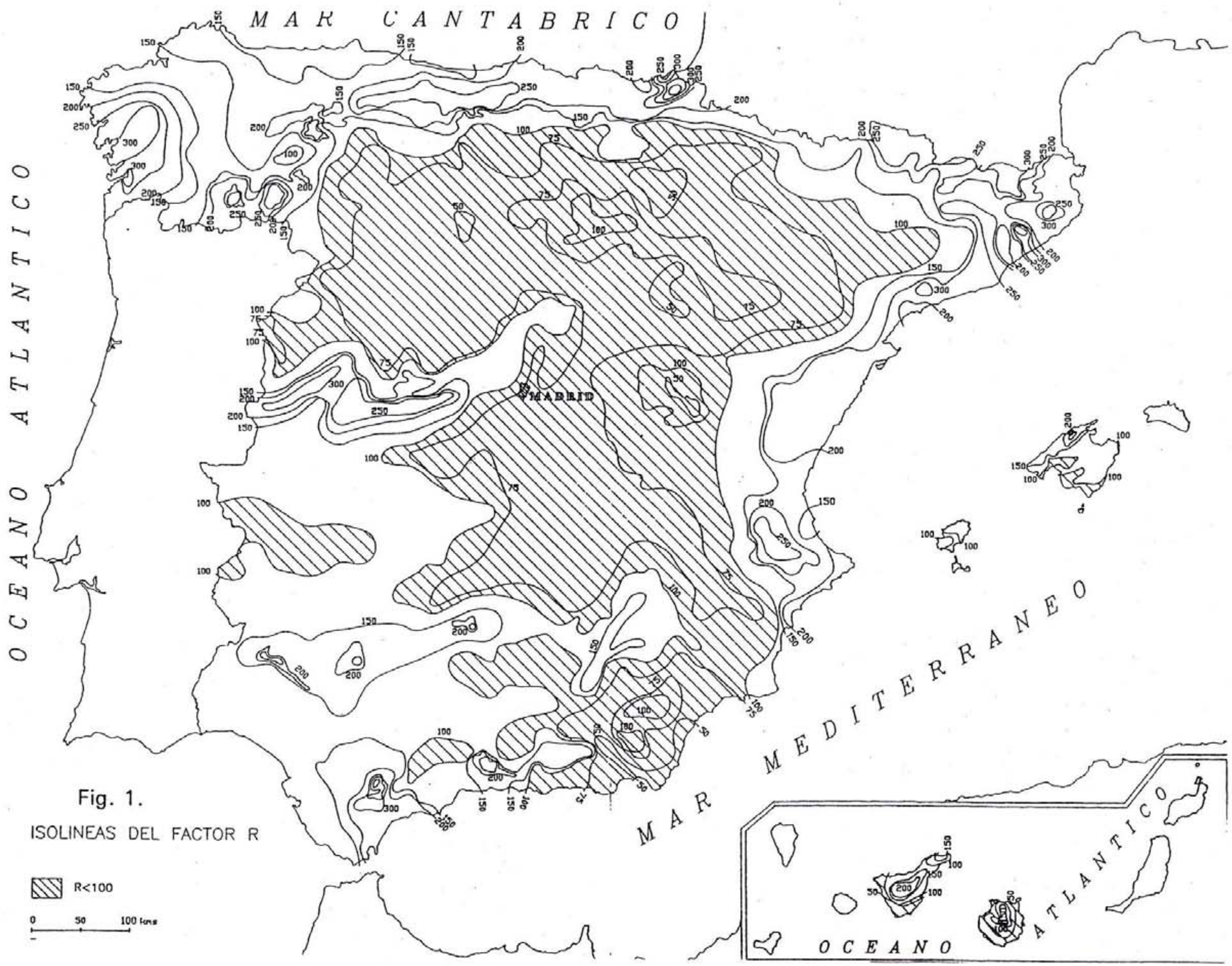

Fig. 1.

ISOLINEAS DEL FACTOR R