Agrociencia Uruguay 2022 | Volume 26 | Number NE2 | Article 1074
DOI: 10.31285/AGRO.26.1074
ISSN 2730-5066

25 years in 25 articles

Technical note

Rainfall Erosivity Factor Update in Uruguay

Actualización del factor erosividad de la lluvia en Uruguay

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Article originally published in:

Agrociencia (Uruguay). 2017;21(2):91-9.
doi: 10.31285/AGRO.21.2.11

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Abstract

The Universal Soil Loss Equation (USLE) and its revised form (RUSLE) are the soil erosion models incorporated into the EROSION 6.0 software. This, in turn, is the soil conservation planning tool used to fulfill the soil conservation regu-lations in Uruguay. The objective of this technical note was to use the methodology proposed by Renard and Freimund (1994) to update the rainfall erosivity factor (R factor) values incorporated into the EROSION 6.0 software. Additionally, it had the following specific objectives: to evaluate the impact of the length of the rainfall data series on the estimation of the R factor and to compare the updated values to the ones that are currently used. The rainfall data base used to estimate the R factor comprises the 1980-2009 period in different Uruguay locations. The equations used in this work allowed to update the R factor, and to obtain R factor values that agree with published R values for the region. The regression line intercept and slope between the 30 yr R factor estimated by both equations did not differ from zero ($P < 0.29$), and one ($P < 0.70$), respectively. The length of rainfall data series affects the R factor value, given the high inter-annual rainfall variability. We recommend using R factors based on 30 years of pluviometric records.

Keywords: rainfall erosivity, USLE, RUSLE, erosion

Resumen

La Ecuación Universal de Pérdida de Suelos (USLE) y su versión revisada (RUSLE) son los modelos de estimación de pérdidas de suelos incorporados en el programa EROSION 6.0. Este último es la herramienta empleada para planificar el uso del suelo y cumplir con la reglamentación vigente en términos de conservación de suelos en Uruguay. El objetivo de esta nota técnica fue emplear la metodología propuesta por Renard y Freimund (1994) para actualizar los valores de factor R en el programa EROSION 6.0. Asimismo, persigue los siguientes objetivos específicos: evaluar el efecto del largo de la serie empleada en la estimación del factor R y comparar los nuevos valores estimados con los que actualmente se emplean. La base de datos empleada para la estimación del Factor R cubre los registros pluviométricos mensuales del período 1980-2009 en diferentes localidades de Uruguay. Las ecuaciones empleadas en este trabajo permitieron actualizar los valores de factor R y obtener magnitudes del mismo que concuerdan con valores de factor R publicados en la bibliografía especializada de la región limítrofe. El intercepto y la pendiente de la línea de regresión entre el factor R promedio de 30 años empleando las Ecuaciones 1 y 2 no fue distinto de cero (P < 0,29) y uno (P < 0,70), respectivamente. El largo de la serie pluviográfica empleada afecta el valor de factor R estimado. Dada la alta variabilidad interanual de las precipitaciones se recomienda emplear las estimaciones basadas en 30 años de información pluviométrica.

Palabras clave: erosividad de la lluvia, USLE, RUSLE, erosión

1. Introduction

The Universal Soil Loss Equation (USLE; Wischmeier and Smith., 1978) and its revised version (RUS-LE; Renard and others, 1997) are the world's most widely used land loss estimation models for land use planning at farm level. They were incorporated into the EROSION 6.0 program (García Préchac, Hill, Clerící, 2005) and their validation for Uruguayan conditions is addressed at length by Durán and García Préchac (2007). Likewise, within the framework of Law 15239, the Directorate of Renewable Natural Resources (RENA-RE) of the Ministry of Livestock, Agriculture and Fisheries (MGAP, by its Spanish acronym) uses this program in the implementation of the Responsible Land Management Use Plans (LMUP). The USLE/RUSLE model estimates the expected long-term annual average erosion on a hillside and has the following form:

$$A = R \times K \times L \times S \times D \times C$$

where:

A is the estimated soil loss ($Mg.ha^{-1}.year^{-1}$);

R is the rainfall erosivity factor and associated runoff ($MJ.mm.ha^{-1}.h^{-1}.year^{-1}$);

K is the soil erodability factor ($Mg.h.MJ^{-1}.mm^{-1}$);

L is the slope length factor;

S is the slope inclination factor;

P is the supporting mechanical practices factor; and C is the land use and management factor.

The EROSION 6.0 program has incorporated R-factor values for different Uruguayan locations in its latest version. However, the climatic information series used for their estimation are not synchronous, their temporal scope is less than 20 years and the methodologies used for their estimation are diverse. In this sense, the estimation equations used for rainfall erosivity were, the proposed by Wischmeier and Smith (1978) and used by Pannone, García and Rovira (1983), modified Fournier index (Arnoldus, 1977) adapted for Uruguay by García Préchac and Clérici (1996), and Sorrondegui (1996). The time series of rainfall information used, contained in the best of situations, information generated up to the late 1990s.

Renard and Freimund (1994) propose different equations for the estimation of the R factor from monthly rainfall information for places outside the United States.

These equations were generated from 132 climate stations that cover an annual average rainfall range between 67 and 1640 mm, and values of the modified Fournier index between 7 and 150 mm. Therefore, two equations are presented to estimate the annual R factor for average annual rainfall regimes greater than 850 mm, or Fournier Index greater than 55 mm.

$$R = 587.8 - 1.219 \times P + 0.004105 \times P2 \quad \text{Eq 1}$$

$$R = 95.77 - 6.081 \times F + 0.4770 \times P2 \quad \text{Eq 2}$$

where

R is the rainfall erosivity factor ($MJ.mm.ha^{-1}\}.h^{-1}.year^{-1}$);

is annual average rainfall (mm); and

is Modified Fournier index (mm).

Uruguay's annual average rainfall was between 1200 and 1600 mm (Castaño and others, 2011) during 1980-2009, whereas the modified Fournier index was between 140-180 mm for the 1991-2000 period (Munka, Gruz and Caffera, 2007). Both the rainfall and the modified Fournier index ranges reported for Uruguay, make Equations 1 and 2 applicable to our conditions.

Since the current information in the EROSION 6.0 program is not updated, and the country has long-term pluviometric information of wide territorial cover, it is relevant to update the R factors. This study aims to update the R factor values in the EROSION 6.0 program through the methodology proposed by Renard and Freimund (1994). It also has the following specific objectives: evaluate the effect of the length of the series used in the estimation of the R factor and compare the new estimated values with those currently used.

Material and methods

The database used to estimate the R factor comes from the monthly rainfall records for the period 1980-2009 in the localities indicated in Table 1. The rainfall base used is the same as the one used by Castaño and others (2011). The R factor was estimated using Equations 1 and 2 proposed by Renard and Freimund (1994). The *P* or *F* value used in the aforementioned equations is the result of the 20-year average. The 20-year moving average was calculated for all localities, in this way, eleven R factor values were generated per locality for each estimation equation. In addition, the R factor was estimated considering the average of the 30 years of the series. The estimates were compared by linear regression. The results are presented in Tables and Figures.

Table 1. Geographical location, average annual rainfall and modified Fournier index for the period 1980-2009.

Latitude	Longitude	Locality	Rainfall Annual average (mm)	Fournier Index
-30,40	-56,5	Artigas	1514	134
-30,20	-57,6	Bella Unión	1452	133
-34,80	-56,0	Carrasco	1175	100
-33,90	-55,5	Cerro Colorado	1278	107
-33,70	-53,5	Chuy	1174	100
-34,50	-57,8	Colonia	1150	100
-32,90	-54,3	Dionisio	1330	113
-33,40	-56,5	Durazno	1257	107
-34,10	-56,1	Florida	1229	104
-33,40	-54,5	J.P. Varela	1580	134
-33,30	-57,1	Marincho	1165	101
-32,40	-54,2	Melo	1395	118
-33,30	-58,1	Mercedes	1181	105
-33,50	-57,8	Palmitas	1223	109
-32,60	-57,4	Paso de la Cruz	1213	107
-32,80	-56,5	Paso de losToros	1315	112
-32,20	-58,1	Paysandú	1234	113
-33,90	-56,8	Pintos	1183	102
-34,90	-56,2	Prado	1162	99
-35,00	-55,0	Punta del Este	1132	96
-30,89	-55,5	Rivera	1602	139
-34,50	-54,3	Rocha	1264	107
-31,40	-58,0	Salto	1334	123
-31,70	-56,0	Tacuarembó	1476	127
-30,40	-57,5	Tomás Gomensoro	1483	134
-33,20	-54,4	Treinta y Tres	1419	119
-33,50	-57,0	Trinidad	1263	108
-31,30	-57,4	Valentín	1310	118

Results

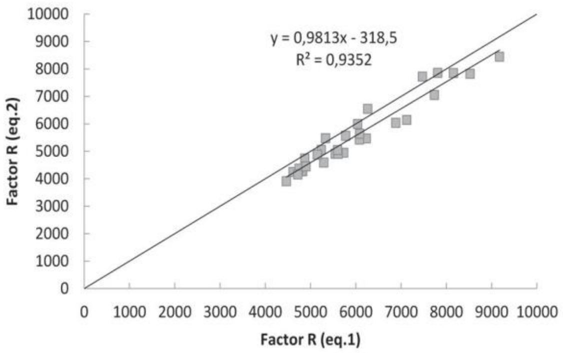
Table 2 presents the R factor values estimated according to Equation 2 for the average of the 20-year moving series and the 30-year series. The town of Tomás Gomensoro reached the maximum R factor (9461 MJ.mm.ha^{-1}.h^{-1}.year^{-1}), while Punta del Este presented the minimum (3602 MJ.ha^{-1}.h^{-1}.year^{-1}), both in the 1986-2005 period. Of all the localities, 53% reached the highest rainfall erosivity values when considering the 1983-2002 and 1984-2003 periods. 27% of localities peaked between 1990-2009. 80% of the minimum R factor values occurred when considering the periods 1980-1999 and 1981-2000. By using Equation 1 (data not presented) the maximum value of R factor occurred in Rivera in the 1984-2003 period (9698 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$), and the minimum in Punta del Este in the 1980-1999 period (4076 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$). Of the evaluated stations, 73% had their maximum R value when considering the period 1983-2002, or 1984-2003. While 77% of the stations presented the minimum estimation when considering the 1980-1999, or 1981-2000 periods.

Table 2. Average R factor for the 20-year moving series and for the 30-year series in different localities using Equation 2.

Locality	1980-1999	1981-2000	1982-2001	1983-2002	1984-2003	1985-2004	1986-2005	1987-2006	1988-2007	1989-2008	1990-2009	1980-2009
Artigas	***8033***	8103	8435	9130	***9187***	8692	8693	8134	8040	8055	8383	7852
Bella Unión	***7665***	7929	8261	8903	9008	8957	***9050***	8546	8645	8555	8807	7724
Carrasco	4123	***3935***	4074	*4419*	4320	4238	4165	4138	4307	4095	4247	4274
Cerro Colorado	4689	***4633***	4733	5096	5030	4854	4849	4836	4974	4868	*5221*	4951
Chuy	***4587***	4552	4444	4433	4461	***4142***	4292	4235	4352	4188	4324	4286
Colonia	***4246***	4354	4478	4710	***4846***	4738	4624	4458	4716	4433	4353	4248
Dionisio	***5958***	6317	6442	***7032***	6945	6379	6539	6220	6186	6106	6260	5469
Durazno	4745	4611	4718	4989	***5130***	4816	4783	***4588***	4833	4725	4979	4912
Florida	4479	***4276***	4398	4729	4624	4485	4432	4454	***4785***	4578	4754	4592
J.P. Varela	***6458***	6664	6887	7262	7529	7143	7445	7260	7816	7985	***8444***	7825
Marincho	***3720***	3759	3971	4356	4509	4197	4194	4108	4501	4349	***4641***	4368
Melo	***5790***	5814	6166	6527	***6574***	6276	6398	6171	6314	6375	6574	6038
Mercedes	***4467***	4476	4661	5025	***5207***	4807	4845	4827	5084	4834	5077	4739
Palmitas	***4701***	4701	5024	5410	***5481***	5054	4962	5011	5414	5127	5411	5053
Paso de la Cruz	***4546***	4583	4841	5322	***5474***	5145	5147	4906	5200	5071	5368	4882
Paso de los Toros	5141	***5131***	5216	5741	5928	5612	5750	5604	5936	5772	***5997***	5430
Paysandú	***5130***	5165	5383	5817	5884	5792	*5964*	5712	5932	5651	5831	5478
Pintos	3923	***3821***	3936	4389	4438	4223	4261	4214	4815	4619	***4954***	4453
Prado	4097	4053	4167	***4413***	4347	4266	4162	4066	4232	***4020***	4095	4158
Punta del Este	3615	3701	3771	3823	3814	3696	***3602***	3700	3940	3904	***4085***	3911
Rivera	8362	***8144***	8497	9049	***9201***	8891	8739	8330	8303	8225	8701	8445
Rocha	***4513***	4665	4749	4919	4840	4825	4921	4863	***5030***	4896	4991	4910
Salto	6036	***5954***	6132	6895	***7286***	7195	7111	6761	7166	6995	7158	6548
Tac-uarembó	***6819***	6960	7199	8063	***8327***	7938	8039	7595	7526	7361	7531	7053
Tomás Gomen-soro	***7685***	7923	8404	9340	9435	9387	***9461***	8919	8804	8769	9006	7858
Treinta y Tres	***5808***	5952	6101	6517	6562	6187	6510	6351	6578	6685	***6867***	6142
Trinidad	***4807***	4832	4920	5256	***5393***	5077	5008	4847	5192	5056	5260	5048
Valentín	6493	6517	6735	7462	***7523***	7290	6650	6198	6261	6079	***6053***	5996
Valle Edén	5433	5319	5297	5525	***5570***	5175	5391	***4975***	5130	5135	5528	5640
Young	***5194***	5213	5253	5944	6131	5844	5985	5847	6105	5838	***6137***	5564

Figure 1 shows the relationship between the 30-year average R factor using Equations 1 and 2. The intercept (-318.5) does not differ from zero (P<0.29), and the regression slope (0.9813) does not differ from one (P<0.70).

Figure 1. Relationship between 30-year average erosivity (MJ.mm.ha^{-1}.h^{-1}.year^{-1}) estimated with equations 1 and 2.



Figures 2 and 3 show the relationship between the average erosivity of 30 and 20 years (1990-2009) estimated with Equations 1 and 2, respectively. The intercept (-519.9) and the regression slope (1.11) between the estimated rainfall erosivity from the 30-year and 20-year series (1990-2009) with Equation 1 are different from zero (P<0.02) and one (P<0.002), respectively. This is repeated when using Equation 2 (Figure 3), being the intercept (-457.8) and the slope of the regression line (1.14), different to zero (P<0.03), and one (P<0.0003), respectively.

Table 3 shows the values of rainfall erosivity currently used by the EROSION 6.0 program and those estimated from 20 (1990-2009) and 30 years (1980-2009) period with Equation 2. Erosivity from the estimated rainfall is smaller in 7 and 9 localities when considering the average of 20 or 30 years, respectively. The greatest decrease occurs in the locality of Durazno, -27 and -28 %, when considering 20 or 30 years, respectively. Meanwhile, Treinta y Tres is the locality with the highest erosivity increase, being 49%, or 33% depending on the period considered. When compared using Equation 1, the estimated erositivity decreases regarding the value used at the moment in 7 and 8 localities when considering the average (1990-2009), or the 30 years of the series, respectively. The greatest decrease occurs in the towns of Durazno (-20%) and Paysandú (-19%), when 20 or 30 years are considered, respectively. The maximum increase is located in the town of Treinta y Tres, being 66% and 54% when considering the average of the period 1990-2009, or the 30 years of the series, respectively.

Figure 2 Relationship between 30-year average erosivity (MJ.mm.ha^{-1}.h^{-1}.year^{-1}) and estimated with Equation 1 for the period 1990-2009.

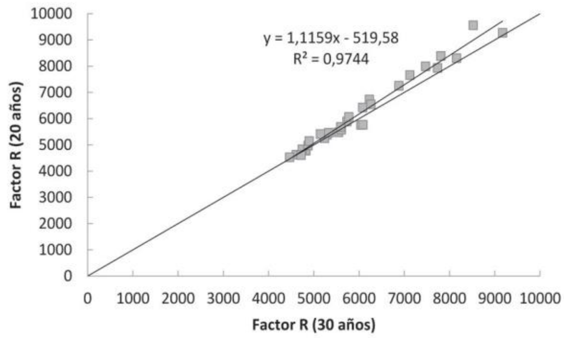


Figure 3 Relationship between 30-year average erosivity (MJ.mm.ha^{-1}.h^{-1}.year^{-1}) and estimated with Equation 2 for the period 1990-2009.

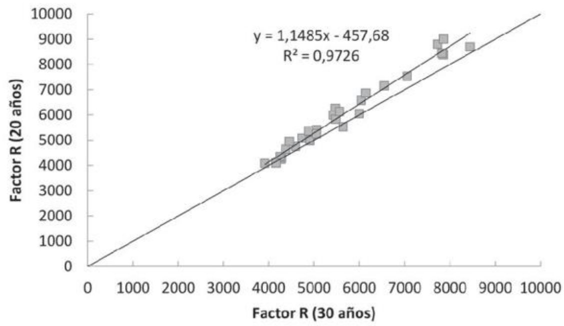


Table 3. R factors included in the EROSION 6.0 program and estimated for the period 1990-2009 and 1980-2009 with Equation 2 for different localities.

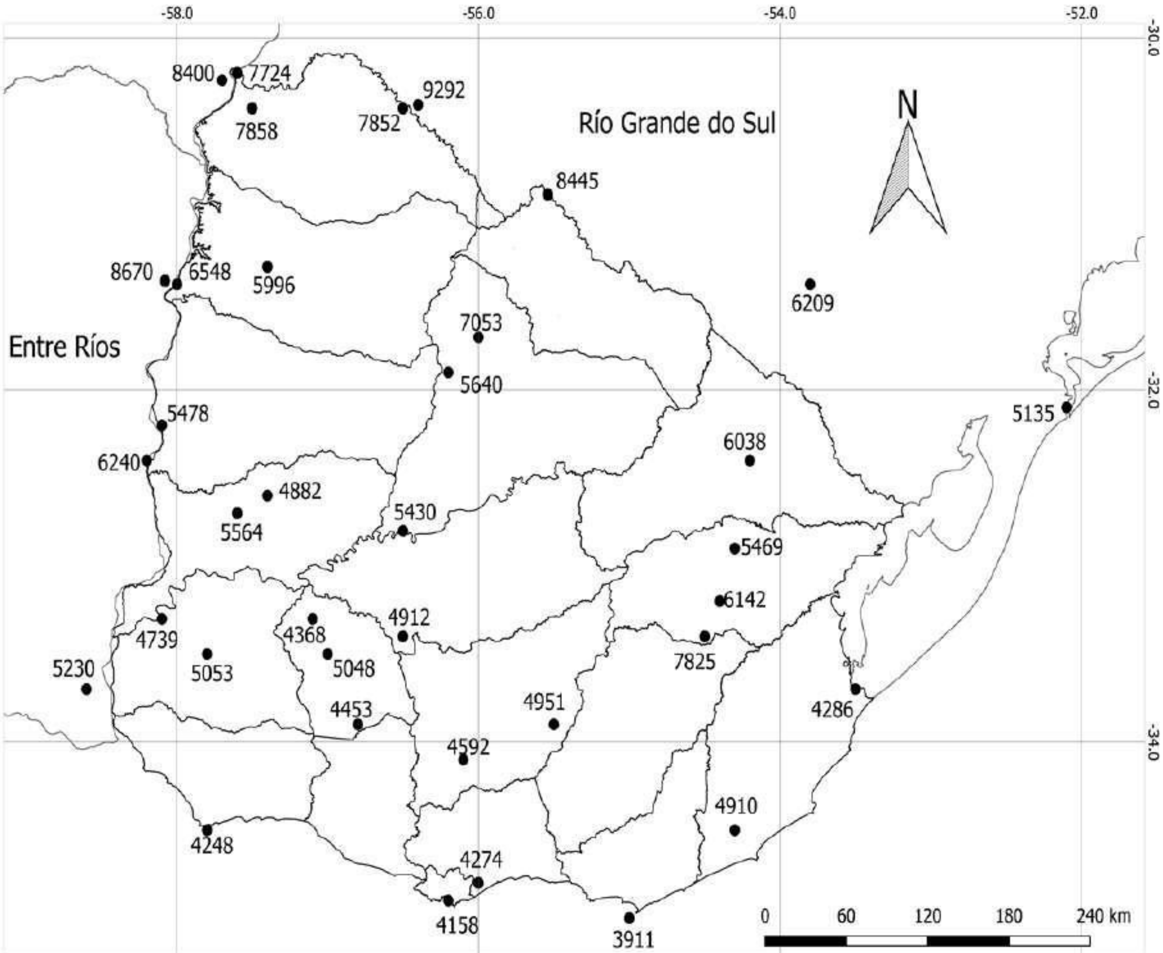
	EROSION6.0	1990-2009	1980-2009
Artigas	8800	8383	7852
Bella Unión	6850	8807	7724
Colonia	4920	4353	4248
Durazno	6830	4979	4912
Melo	5550	6574	6038
Mercedes	5540	5077	4739
Montevideo	3820	4095	4158
Paso de los Toros	6380	5997	5430
Paysandú	6590	5831	5478
Punta del Este	3350	4085	3911
Rivera	9350	8701	8445
Rocha	4960	4991	4910
Salto	6620	7158	6262
Tacuarembó	6500	7531	7053
Treinta y Tres	4620	6867	6142

Discussion

Rainfall erosivity increases from the south to the north of the country (Figure 4), with the lowest values being in Punta del Este. The magnitude of the estimated erosivity (Table 2) is similar to that found by Saluso (2006) in meteorological stations located east of the Province of Entre Ríos, northeast of the Province of Buenos Aires and southeast of the Province of Corrientes, Argentina (Figure 4). Saluso (2006) indicates that the isoerodent 5000 (MJ.mm.ha^{-1}.h^{-1}.year^{-1}) is located slightly south of the estuary of the Paraná River, and the isoerodent 9000 (MJ.mm.ha^{-1}.h^{-1}.year^{-1}) slightly north of Monte Caseros, Corrientes. Saluso assigns an erosivity value of 8400 (MJ.mm.ha^{-1}.h^{-1}.year^{-1}) to this location, considering the 1950-2005 period. Our estimations for the locality of Bella Unión, using the Renard and Freimund (1994) methodology, are in the range of 7231 to 9050 (MJ.mm.ha^{-1}.h^{-1}.year^{-1}), depending on the length and years of the series, therefore considered as estimation equation (Table 2). Peñalva Bazzano, Eltz and Cassol (2007) report for the locality of Quaraí, Rio Grande do Sul, Brazil, bordering Artigas, an annual average erosivity of 9292 (MJ.mm.ha^{-1}.h^{-1}.year^{-1}) for the 1966-2003 period, with an annual maximum and minimum of 22827 and 2239, respectively (Figure 4). Our estimations for the town of Artigas range between 7972 and 9187 according to the length, years of the series and equation used. Erosivity in Colonia varies between 4246 and 4976 (MJ.mm.ha^{-1}.h^{-1}.year^{-1}), Saluso's isoerodent 5000 (2006) is located slightly south of the estuary of the Paraná River.

Despite the increase in erosivity towards the north of the country, to the east of the Cuchilla Grande there is a rainfall erosivity gradient that decreases towards Laguna Merín. In the southern area of the State of Rio Grande do Sul close to the border with Uruguay, a similar pattern can be seen.

Figure 4. Geographical distribution of the 30-year average R factor estimated with Equation 2. Note: The R factor values of Argentina were taken from Saluso (2006) and those of Brazil from Peñalva Bazzano, Eltz and Cassol (2007, 2010).



The erosivity in the port town of Rio Grande is 5135 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$ (Peñalva Bazza-no, Eltz and Cassol, 2010), while in Hulha Negra, next to Bagé, the value is 6209 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$ (Martins and others, 2009) (Figure 4). The maximum value in the eastern region of the country is found in José Pedro Varela, the intermediate ones in Melo and Treinta y Tres, and the minimums in Rocha and Chuy (Table 2). Although this pattern responds to the average annual rainfall (Castaño and others, 2011), its occurrence has a strong impact on the short-term when planning land use with the USLE/RUSLE model. The spatial variation pattern of rainfall erosivity in Uruguay observed in our study is consistent with data of studies carried out in bordering areas of the neighboring countries.

The length of the historical series used affects the magnitude of the estimated R factor (Figures 2 and 3), with a greater average when the series shortens from 30 to 20 years. The R factor values used in RUSLE for the United States are based on historical series that cover at least 22 years of records. Renard and others (1997) suggest the use of more extensive historical series in regions with high interannual rainfall variability. This is Uruguay's rainfall regime condition, so in our opinion, it would be convenient to use estimates based on 30 years of rainfall records.

When comparing the estimations of the R factor values generated with the two equations and the currently used values, they present a decrease in the central area of the country (Durazno) and a considerable increase in the east of the country. The reasons for the increase or decrease of the R factor exceed the objectives of this study. However, the impact of these changes on land loss estimates and consequently on land use planning, particularly in the east of the country, can be counterbalanced by the adjustment proposed by García Préchac and others (2016). It consists of considering the variation of soil water content in erosion estimates in Uruguay, which was shown to significantly affect them (Hill and others, 2008), and has not yet been incorporated into the EROSION 6.0 program.

Conclusions

The equations used in this study allowed updating the R factor values used by the EROSION 6.0 program, and obtaining numbers that agree with R factor values published in the specialized literature of the bordering region. The R factors estimated with the two equations, based on 30 years of rainfall information, were not different. The length of the pluviometric series affects the estimated R factor value, but given the high interannual rainfall variability, it is recommended to use estimates based on 30 years of information.

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