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Australian *Journal* of Soil Research

VOLUME 40, 2002

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Aust. J. Soil Res., 2002, **40**, 887–901

Spatial and seasonal distribution of rainfall erosivity in Australia

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Abstract

Spatially distributed rainfall erosivity and its seasonal distribution are needed to use the revised universal soil loss equation (RUSLE) for erosion risk assessment at large scale. An erosivity model and 20-year daily rainfall data at 0.05° resolution were used to predict the *R*-factor and its monthly distribution for RUSLE in Australia. Predicted *R*-factor values were compared with those previously calculated using pluviograph data for 132 sites around Australia. The daily erosivity model was further evaluated for 43 sites where long-term pluviograph data were available. Predicted and calculated monthly distributions of the *R*-factor were compared for these 43 sites. For the 132 sites where *R*-factor values were compiled from previous investigations, the model efficiency was 0.81 with root mean squared error (rmse) of 1832 MJ.mm/(ha.h.year), or 47.5% of the mean for the 132 sites. For the additional 43 sites, the coefficient of efficiency was 0.93 with a 12.7 mm rainfall threshold, and 0.94 when all storms were included in the calculations. The rmse was 908 MJ.mm/(ha.h.year), or 28.6% of the mean for the 43 sites with a zero rainfall threshold. The prediction error for monthly distribution of the *R*-factor was 2.3% with a zero threshold and 2.5% with 12.7 mm threshold. This and previous studies have shown that the daily rainfall erosivity model can be used to accurately predict the *R*-factor and its seasonal distribution in Australia. Digital maps were produced showing the spatial and seasonal distribution of the *R*-factor at 0.05° resolution in Australia. These maps have been used to assess rill and sheet erosion rate at the continental scale.

Introduction

Erosion risk assessment is required for land management and conservation planning. The most commonly used method for predicting the average soil loss rate at large-scale remains the universal soil loss equation (USLE, Wischmeier and Smith 1978) and its recent modification, the Revised USLE (RUSLE, Renard *et al.* 1997). To use the USLE/RUSLE for soil loss prediction or to determine soil erodibility for the USLE/RUSLE at a particular site, the numerical value of a rainfall and runoff factor, known as the *R*-factor, is needed. The *R*-factor is a measure of rainfall erosivity and is defined as the mean annual sum of individual storm erosion index values, EI_{30}, where E is the total storm kinetic energy and I_{30} is the maximum 30-min rainfall intensity. When factors other than rainfall are held constant, soil losses are directly proportional to the magnitude of rainfall erosivity (Wischmeier and Smith 1958, 1978). The *R*-factor represents the climatic influence on water-related soil erosion, and therefore can be used to quantify broad-scale, climate-driven, soil erosion potential. Monthly distribution of the rainfall erosivity is needed to determine a weighted cover factor for the RUSLE.

To compute storm EI_{30} values, continuous rainfall intensity data at time intervals of less than 30 min are needed. Wischmeier and Smith (1978) recommended that at least 20 years of rainfall intensity data at short time intervals be used so that the natural climatic variations can be accommodated. Rainfall intensity data at short time intervals are available either in digitised pluviographs (commonly known as break-point data) or discrete rainfall rates associated with tipping bucket rain gauge. For simplicity, we call, henceforth, rainfall

 10.1071/SR01117 0004-9573/02/060887

intensity data at short time intervals (<30-min) pluviograph data, as distinct from daily rainfall data. Spatial and temporal coverage of pluviograph data is usually limited. When available, pluviograph data are often incomplete and the recorded period is mostly short. Daily rainfall data, in contrast, are more widely available and for longer periods. It is therefore desirable to be able to estimate the *R*-factor and its monthly distribution, needed to apply the USLE/RUSLE for soil erosion prediction, from daily rainfall amounts.

In areas where long-term pluviograph data are not available, the *R*-factor may be estimated using mean annual rainfall or the Modified Fournier Index (e.g. Stocking and Elwell 1976; Arnoldus 1977; Roose 1977; Renard and Freimund 1994; Yu and Rosewell 1996*c*). Alternatively, 2-year, 6-h rainfall intensity probability values may be used to estimate the *R*-factor (Ateshian 1974; Wischmeier 1974; Wischmeier and Smith 1978; Rosewell 1993*a*). These approaches, however, do not allow determination of the seasonal distribution of rainfall erosivity. Information on seasonal distribution is needed to calculate average annual cover and management factors in the USLE/RUSLE (Renard *et al.* 1997). Seasonal distribution of rainfall erosivity is important for assessing erosion hazards. When peak rainfall erosivity coincides with exposure of bare soils through, for example, bare fallow, forest harvesting, or land clearing at construction sites, soil erosion risk is increased considerably. To adequately represent the erosive potential of rainfall for each temporally distinctive period, it is recommended that the USLE/RUSLE cover and management factor needs to be calculated on 15-day or monthly basis (Renard *et al.* 1997). At the continental scale, problematic to the annual-based application of the RUSLE is the pronounced wet–dry precipitation regime in the tropics and in regions with a Mediterranean climate.

Some work on the estimation of *R*-factor and its monthly distributions has been done in the past for most States of Australia. Isoerodent maps showing lines of equal erosivity were published for Victoria (Garvin *et al.* 1979), Queensland (Rosenthal and White 1980), Western Australia (McFarlane *et al.* 1986), New South Wales (Rosewell and Turner 1992), and South Australia (Yu and Rosewell 1996*b*). In addition, a relationship between the *R*-factor and 2-year, 6-h rainfall intensity was developed for a number of sites in Australia (Rosewell and Turner 1992; Rosewell 1993*a*). Such a relationship has been used to estimate rainfall erosivity for all States and territories based on rainfall intensity data published in *Australian Rainfall and Runoff* (Pilgrim 1987; Rosewell 1993*b*, 1997). The quality of the estimated *R*-factor depends on the quality of the limited pluviograph data and it is also known that rainfall intensity data cannot be used to estimate the seasonal distribution of rainfall erosivity. To overcome the problem with limited pluviograph data and the inability to estimate the seasonal distribution of rainfall erosivity, a model using daily rainfall data has been tested for both temperate and tropical regions of Australia (Yu and Rosewell 1996*a*, 1996*b*; Yu 1998). Regional relationships of model parameters were also developed to allow prediction of the *R*-factor and its monthly distribution from daily rainfall anywhere in Australia (Yu 1998). However, despite the increasing demand for environmental management, an up-to-date, high spatial resolution and consistent national digital map of *R*-factor and its seasonal distribution is currently lacking.

There are 2 major objectives of this study. The first is to assess the accuracy of estimating the *R*-factor and its monthly distribution from daily rainfall amounts. The second is to provide high resolution, up-to-date maps of *R*-factor and its monthly distribution across Australia that can be readily used by soil conservationists and environmental managers. In this paper, the daily erosivity model of Yu and Rosewell (1996*a*, 1996*b*) is tested for 132 sites around Australia by comparing the modelled *R*-factor with that compiled from literature based on pluviograph data. *R*-factor and its monthly distribution are further evaluated at 43 sites where long-term pluviograph data are used. The 43 sites cover a wide range of climates across Australia. No calibration of model parameters was attempted so that model errors could be independently assessed. An isoerodent map and maps showing monthly variation in rainfall erosivity are then produced using high-resolution daily rainfall data at 0.05° for Australia.

Methods

Data

Grid daily rainfall data

The model was applied to the Australian continent using 0.05° resolution daily rainfall data interpolated by Queensland Department of Natural Resources and Mines. The description of daily rainfall interpolation can be found in Jeffrey *et al.* (2001). Ordinary kriging was first used to spatially interpolate monthly rainfall values. Then, for each grid cell, the daily distribution of rainfall in the month was calculated by accessing the rainfall record from the station nearest to the point of interest, and partitioning the interpolated monthly rainfall onto individual days according to the historical record of daily rainfall at the nearest station. In this study, 20 years of grided daily rainfall data from 1 January 1980 to 31 December 1999 were used. Mean monthly rainfall, needed by the erosivity model to estimate model parameters, was calculated using the same daily rainfall data.

Pluviograph data

Two types of pluviograph sites were used in this study. The first consisted of 132 sites around Australia (Fig. 1). These *R*-factor values were compiled from previous studies (Rosenthal and White 1980; McFarlane

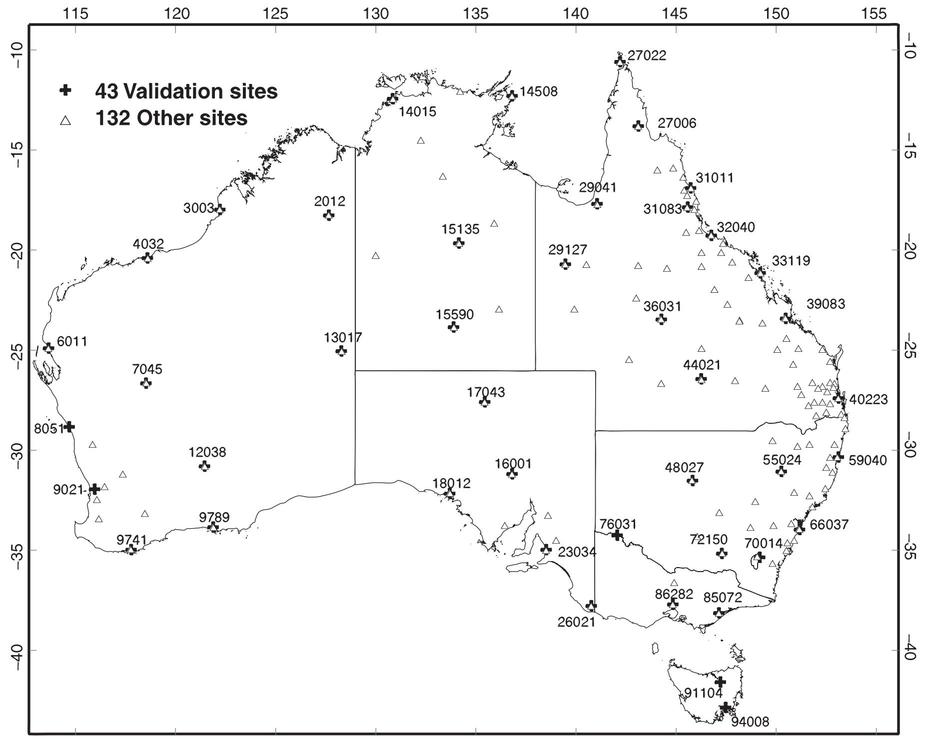

Fig. 1. Location map showing the 132 sites where *R*-factors were compiled from previous studies (△) and the 43 sites where long-term pluviograph data were used in this study (✚). The station numbers of the 43 sites are shown.

*et al.*1986; Yu and Rosewell 1996*a*, 1996*b*; Yu 1998). The *R*-factor was calculated by different researchers using pluviograph data available at the time. Different storm energy equations and algorithms were used to calculate the *R*-factor. Multiple *R*-factor values at the same sites were used as either different energy equations or period of rainfall data were used by different researchers. In some cases, the pluviograph data were incomplete or the record length was particularly short (Rosenthal and White 1980; McFarlane *et al.* 1986). In total, 153 *R*-factor values were compiled. All these *R*-factor values were used in this study to compare with the *R*-factor predicted using the 20-year grid daily rainfall data to assess conservatively the magnitude of model errors. No attempt was made to compare seasonal *R*-factor distribution for these sites as insufficient information about seasonal distribution was available from previous studies.

The second group contained 43 pluviograph sites distributed throughout Australia (Fig. 1). They were selected not only for their spatial coverage across Australia but also for their record length (at least 20 years) and their period of operation (mostly covering the period from 1980 to 1999). These sites cover all the major climate zones in Australia with the mean annual rainfall ranging from 271 mm at Giles to 2431 mm at Koombooloomba (Bureau of Meteorology 1989). Pluviograph data at 6-min intervals were extracted from Bureau of Meteorology archives for these 43 sites. *R*-factor and its monthly distribution were calculated using the RECS program (Yu and Rosewell 1998). Recommendations for calculating *R*-factor using pluviograph data from the RUSLE manual were strictly followed (Renard *et al.* 1997). Dry periods of 6 h or longer were used to separate storm events; monthly erosivity was the sum of EI_{30} values of all storm events in the month; and the energy equation of Brown and Foster (1987) was used to determine total storm energy. Details about these 43 sites are presented in Table 1.

Model and method of analysis

The model to estimate the sum of EI_{30} values for the month j, $\hat{E}_j$, using daily rainfall amounts can be written in the form (Yu and Rosewell 1996*a*):

$$\hat{E}_j = \alpha\left[1+\eta\cos(2\pi f j-\omega)\right]\sum_{d=1}^{N} R_d^{\beta} \qquad \text{when} \quad R_d > R_0 \tag{1}$$

where R_d is the daily rainfall amount, R_0 is the threshold rainfall amount to generate runoff, and N is the number of days with rainfall amount in excess of R_0 in the month, and α, β, η, and ω are model parameters. The sinusoidal function with a fundamental frequency $f = 1/12$ is used to describe the seasonal variation of the coefficient. It is used to describe the seasonal variation of rainfall erosivity for a given amount of daily rainfall.

Equation 1 differs from previous models in 2 important aspects. In previous models using daily or event rainfall amounts, EI_{30} was estimated for individual events and model parameters were determined using log-linear or non-linear regression techniques (Richardson *et al.* 1983; Elsenbeer *et al.* 1993; Posch and Rekolainen 1993). Since monthly erosivity is much less variable than event EI_{30} and only monthly values are needed to compute the *R*-factor and its monthly distribution, Eqn 1 contains more relevant parameters. Parameters of Eqn 1 are optimised on a monthly basis to ensure minimum bias. Secondly, the sinusoidal term was introduced to take into account the possibility of having different storm types in different seasons. This term allows erosivity for a given amount of rain to vary seasonally.

This model has a maximum of 5 parameters: α, β, η, ω, and R_0. The parameter ω is set at $\pi/6$, implying that for a given amount of daily rainfall the corresponding rainfall intensity is the highest in January, when the temperature is the highest for most parts of the continent. Two different values of rainfall threshold R_0 (12.7 mm and 0 mm) were used for the 43 sites in this study. In the USLE, Wischmeier and Smith (1978) suggested using 12.7 mm as the threshold rainfall R_0. When the isoerodent map was prepared for the eastern part of the USA, a rainfall threshold of 12.7 mm was used (Wischmeier and Smith 1978). Most of the previous *R*-factor values presented in Fig. 2 were calculated using R_0 = 12.7 mm. The RUSLE manual has recommended that all storms be included in *R*-factor calculations (Renard *et al.* 1997). Yu (1999) found that the discrepancy in the calculated *R*-factor due to different rainfall thresholds increases as mean annual rainfall decreases because of the high relative contribution of small storm events to the *R*-factor. Two rainfall thresholds were considered in this paper to examine the effects of rainfall threshold on annual *R*-factor and its seasonal distribution at large space scale. To be consistent, the same 2 thresholds were used to calculate the *R*-factor and its seasonal distribution for the 43 sites both using pluviograph data and the daily rainfall erosivity model. Regional relationships were derived using 79 stations located in New South

Wales, South Australia, and the tropics for parameters α, β, η. For the case of R_0 = 12.7 mm, the following sets of equations are used (Yu 1998):

$$\alpha = 0.395\ [1 + 0.098\ \exp(3.26\ \Psi/M_R)] \quad (2)$$

$$\beta = 1.49 \quad (3)$$

$$\eta = 0.29 \quad (4)$$

where M_R is the mean annual rainfall and Ψ is the mean summer rainfall (November to April; Bureau of Meteorology 1989). For the case of R_0 = 0 mm, we use:

$$\alpha = 0.369\ [1 + 0.098\ \exp(3.26\ \Psi/M_R)] \quad (5)$$

while values of β and η as same as Eqns 3 and 4.

Two measures were used to quantify the model performance. Firstly, the predictive capacity of *R*-factor is measured by the coefficient of efficiency, E_c (Nash and Sutcliffe 1970). It is the fraction of total variation in the original data that can be explained by the model:

$$E_c = 1 - \sum_{i=1}^{M} (E_i - \hat{E}_i)^2 / \sum_{i=1}^{M} (E_i - \overline{E})^2 \quad (6)$$

where E_i and $\hat{E}_i$ are the annual *R*-factor calculated using pluviograph data and the daily rainfall erosivity model for site *i*, respectively, $\overline{E}$ is average value of the *R*-factor calculated for all sites considered using pluviograph data. Essentially, E_c is an indicator of how close the scatters of predicted versus actual values are to the 1 : 1 line. It is equivalent to the coefficient of determination (r^2) for linear regression models and can be considered as a measure of model efficiency for any other types of models. E_c is commonly used to assess model performance in hydrology (Loague and Freeze 1985) and soil science (Risse *et al.* 1993; King *et al.* 1996). Secondly, the accuracy of estimated seasonal distribution of rainfall erosivity is assessed by a discrepancy measure, δ. It is defined as the mean absolute difference between actual and estimated seasonal distribution of rainfall erosivity. Let p_j and $\hat{p}_j$ be the percentage contribution of the month *j* to the *R*-factor calculated by the model using pluviograph data and the daily rainfall erosivity model, respectively, then:

$$\delta = \frac{1}{12} \sum_{j=1}^{12} | p_j - \hat{p}_j | \quad (7)$$

In this study, the daily erosivity model is applied to predict the mean annual *R*-factor (averaged annual EI_{30}), and mean monthly EI_{30} values using 20 years daily rainfall data from 1980 to 1999. The SI unit of MJ mm/(ha.h.year) is used for the *R*-factor throughout this paper.

Results and discussion

The *R*-factor predicted using the daily model was compared with that calculated by several previous researchers for 132 sites (Rosenthal and White 1980; McFarlane *et al.* 1986; Yu and Rosewell 1996*a*, 1996*b*; Yu 1998). Figure 2 shows the comparison between the predicted and calculated *R*-factor using pluviograph data. The coefficient of efficiency E_c = 0.81 with root mean squared error (rmse) of 1832 MJ.mm/(ha.h.year), or 48% of the mean and r^2 = 0.82. The average value of predicted *R*-factor for the 132 sites is 3987 MJ.mm/(ha.h.year) compared with 3854 MJ.mm/(ha.h.year) calculated using pluviograph data. No noticeable bias of the model is observed. Figure 3 shows the similar *R*-factor comparison using 2 different values of rainfall threshold R_0 for the 43 sites where long-term pluviograph data were available. With R_0 = 0 mm, the coefficient of efficiency E_c = 0.94 with rmse of 908 MJ.mm/(ha.h.year), or 29% of the mean and r^2 = 0.95. When

Table 1. Station number and names, longitudes, latitudes, pluviograph data availability, mean annual rainfall (MAR) for both the pluviograph data and 20-year daily rainfall, rainfall erosivity calculated using pluviograph data and daily rainfall model with two different rainfall thresholds R_0 (mm), and discrepancy measures δ for 43 selected sites in Australia

Station No.	Station name	Long. (east)	Lat. (south)	Period (year)	MAR (mm)		*R*-factor (MJ mm/(ha.h.year)				δ (%)	
					Pluvio.	1980–1999	Pluviograph data		Daily rainfall model		$R_0 = 12.7$	$R_0 = 0.0$
							$R_0 = 12.7$	$R_0 = 0.0$	$R_0 = 12.7$	$R_0 = 0.0$		
2012	Halls Creek Airport	127°40′	18°14′	1955–2000	601	613	2744	2908	4342	4056	2.0	1.9
3003	Broome Airport	122°14′	17°57′	1948–2000	635	602	4352	4451	5443	5085	1.7	1.5
4032	Port Hedland Airport	118°37′	20°22′	1953–1998	361	317	1265	1322	1815	1696	2.9	2.8
6011	Carnarvon Airport	113°40′	24°53′	1956–1998	268	220	632	682	304	284	2.6	2.5
7045	Meekatharra Airport	118°33′	26°37′	1953–1998	253	253	451	517	473	442	2.9	2.7
8051	Geraldton Airport	114°42′	28°48′	1953–2000	474	451	820	953	467	436	2.2	2.1
9021	Perth Airport	115°58′	31°56′	1961–1998	779	783	1172	1312	897	838	1.4	1.3
9741	Albany Airport	117°48′	34°57′	1965–1998	787	880	557	723	745	696	1.9	1.6
9789	Esperance	121°54′	33°50′	1971–1998	589	601	498	645	549	513	2.7	1.9
12038	Kalgoorlie Boulder Airport	121°28′	30°47′	1939–1999	289	291	402	474	432	404	3.1	2.7
13017	Giles Meteorological Office	128°18′	25°02′	1956–1998	293	271	653	722	828	773	4.7	4.2
14015	Darwin Airport	130°52′	12°25′	1953–2000	1718	1726	13 556	13 856	15 093	14 100	2.0	1.9
14508	Gove Airport	136°49′	12°17′	1966–1998	1318	1359	7677	7884	9471	8848	2.8	2.6
15135	Tennant Creek Airport	134°11′	19°38′	1969–1996	462	363	1915	2026	2181	2037	2.7	2.5
15590	Alice Springs Airport	133°54′	23°49′	1951–1999	329	240	951	1012	712	665	3.6	3.1
16001	Woomera Aerodrome	136°49′	31°09′	1955–1999	201	166	264	315	206	192	6.4	5.0
17043	Oodnadatta Airport	135°27′	27°34′	1961–1985	230	161	430	479	451	421	4.3	4.0
18012	Ceduna Amo	133°43′	32°08′	1954–2000	294	277	264	333	215	201	2.3	2.2
23034	Adelaide Airport	138°32′	34°57′	1967–2000	441	434	285	419	318	297	3.1	2.0

(*continued next page*)

Table 1. (continued)

26021	Mount Gambier Aero	140°47′	37°45′	1942–2000	694	727	406	549	577	539	1.8	1.2
27006	Coen Airport	143°07′	13°46′	1967–1997	1204	1223	6109	6308	10 038	9377	1.4	1.3
27022	Thursday Island Mo	142°13′	10°35′	1961–1993	1793	1682	12 705	12 965	14 282	13 342	1.8	1.7
31083	Koombooloomba Dam	145°36′	17°50′	1960–1997	2592	2431	8060	8210	8100	7567	1.1	2.0
32040	Townsville Aero	146°46′	19°15′	1953–1999	1083	946	6375	6532	7108	6640	1.5	1.5
33119	Mackay Mo	149°13′	21°07′	1959–1997	1599	1451	9475	9707	9130	8529	1.6	1.6
36031	Longreach Aero	144°17′	23°26′	1966–1997	454	395	1773	1873	1637	1529	1.7	1.4
39083	Rockhampton Aero	150°29′	23°23′	1939–1999	821	709	2877	3003	2773	2590	2.7	1.5
40223	Brisbane Aero	153°07′	27°23′	1949–1998	1166	1151	4706	4901	4320	4036	2.2	1.6
44021	Charleville Aero	146°16′	26°25′	1953–1999	506	444	1214	1315	1205	1126	1.5	1.7
48027	Cobar Mo	145°50′	31°29′	1962–2000	414	366	1030	1124	746	697	3.4	2.5
55024	Gunnadah	150°16′	31°02′	1946–1997	638	638	1433	1574	1524	1424	2.8	2.1
59040	Coffs Harbour Mo	153°07′	30°19′	1960–2000	1671	1687	7101	7348	6708	6266	1.5	1.6
66037	Sydney Airport Amo	151°10′	33°56′	1962–2000	1124	1084	3548	3746	2976	2780	2.7	3.0
70014	Canberra Airport	149°12′	35°19′	1937–2000	613	663	766	901	1418	1325	2.8	2.6
74114	Wagga Wagga Amo	147°18′	35°08′	1947–1996	586	575	834	980	822	768	2.9	1.4
76031	Mildura Airport	142°05′	34°14′	1953–1998	295	283	378	452	309	289	2.9	2.4
85072	East Sale Airport	147°09′	38°06′	1953–2000	592	588	512	654	857	801	1.7	2.4
86282	Melbourne Airport	144°51′	37°41′	1970–2000	535	529	644	786	684	639	2.3	2.8
91104	Launceston Airport	147°13′	41°33′	1938–2000	665	565	440	595	675	631	2.6	3.2
94008	Hobert Airport	147°30′	42°50′	1960–2000	530	483	719	830	604	564	5.7	1.5

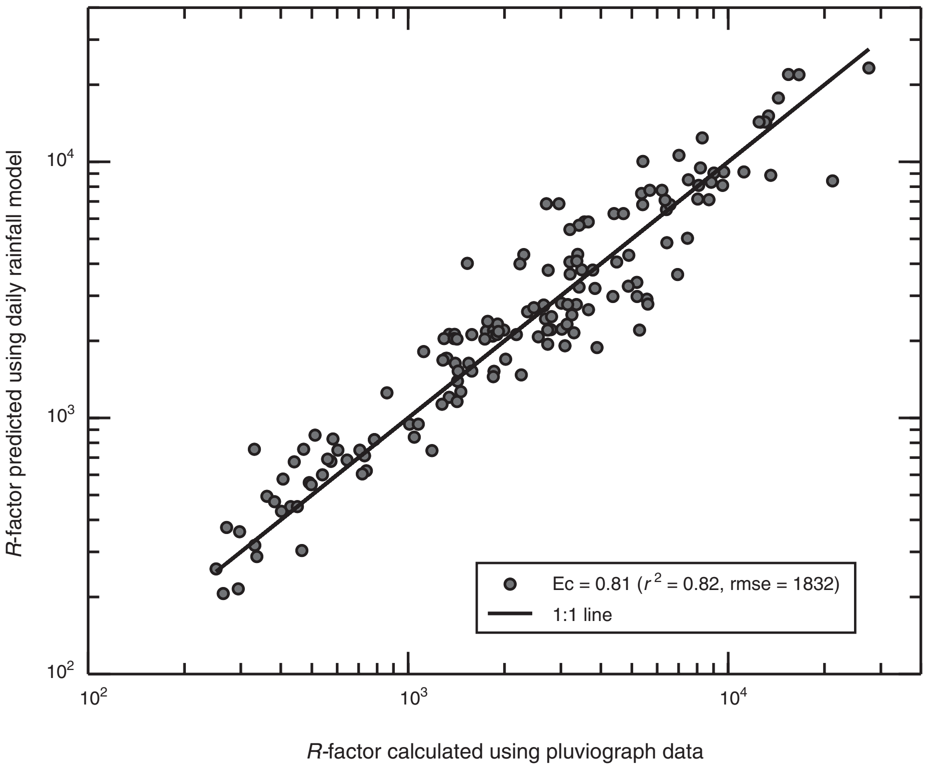

Fig. 2. Comparison between R-factors predicted using 20-year daily rainfall data and those calculated using pluviograph data by previous researches for the 132 locations. Multiple values for the same rainfall gauge stations given by different authors using different period of rainfall data are all included. The units of R-factor and rmse are MJ mm/(ha.h.year).

R_0 = 12.7 mm, the coefficient of efficiency E_c = 0.93 with rmse of 946 MJ.mm/(ha.h.year), or 31% of the mean and r^2 = 0.95. Lowering the rainfall threshold from 12.7 mm to 0 mm increases the R-factor. This is true for both the R-factor calculated from pluviograph data and that predicted from daily rainfall. The amount of increase is smaller for areas with large R-factor values [<1% on average when R >1000 MJ mm/(ha.h.year)] than areas with a relatively smaller R-factor [over 10% on average when $R \leq$ 1000 MJ mm/(ha.h.year)]. For R-factor <1000 MJ mm/(ha.h.year), the amount of increase is slightly larger for the daily rainfall model compared with that based on pluviograph data. In general, R-factor predicted by the daily rainfall model compares well with various R-factors calculated using pluviograph data.

Table 1 summarises of the R-factor calculated based on pluviograph data and daily rainfall erosivity model together with the discrepancy measure δ for all 43 sites. Overall the agreement is better for the sites with higher R-factor values. The average discrepancy measure δ is 2.3% when R_0 = 0 mm and 2.5% when R_0 is set to 12.7 mm. The discrepancy measure δ ranges from 1.2% at Mount Gambier to 5% at Woomera when R_0 = 0, and from 1.1% at Koombooloomba to 6.4% at Woomera when R_0 is set to 12.7 mm. The predicted R-factor and its monthly distribution are both slightly improved by using threshold R_0 = 0 mm. It was also found that the daily rainfall model works almost equally well for the

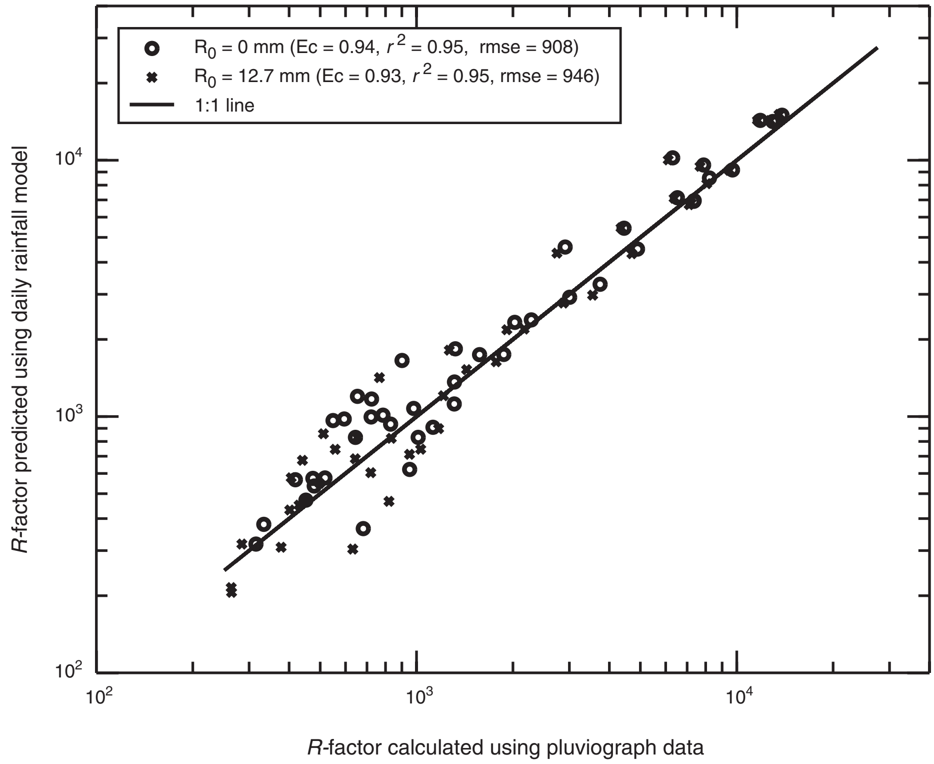

Fig. 3. Comparison between *R*-factors predicted using 20-year daily rainfall data and those calculated using 6-min pluviograph data for two different rainfall thresholds for the 43 sites.

winter rainfall area, e.g. Perth, Adelaide, and Albany, where modelling erosivity from the rain total is challenging because the seasonal distributions of rainfall and rainfall erosivity could be out of phase. Six sites, representing different climatic regimes, were selected to illustrate the model predictive capacity of seasonal distribution of rainfall erosivity. The 6 sites are: Canberra, temperate climate with a uniform rainfall throughout the year; Perth, dominant rainfall in winter; Brisbane, subtropical climate; Darwin, tropical climate with a distinct wet season in summer. Koombooloomba has the highest mean annual rainfall among the 43 sites, while Giles is the driest site. Figure 4 shows the calculated and predicted monthly rainfall erosivity for these 6 sites. Except for Giles, the estimated seasonal patterns of rainfall erosivity for the other 5 sites match closely those based on long-term 6-min pluviograph data with the discrepancy measure *d* ranging from 1.1% to 2.8%. The larger discrepancy at Giles (4.2%) is due to a lack of storms in this arid environment and partially due to larger interpolation error in the grided rainfall data. The first problem could be relatively easy to fix by using longer periods of record. Fixing the second problem is more difficult. In the arid areas, the rain gauge density is sparse. This makes the interpolation of daily rainfall data across the 0.05° grid fundamentally difficult and likely to produce larger errors. Sites similar to Giles where rainfall is low also include Woomera (16001), Oodnadatta (17043), and Alice Springs (15590). The sites in dry areas tend to have above average discrepancy in the seasonal distribution of rainfall erosivity.

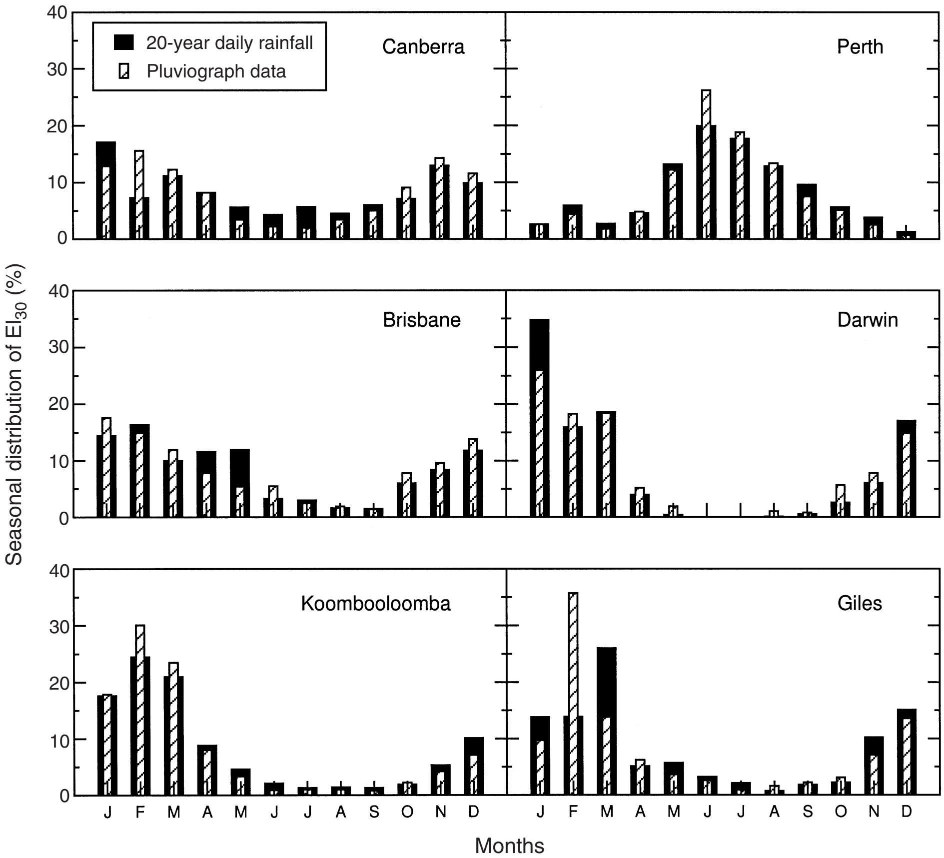

Fig. 4. Comparison between monthly *R*-factors distributions using 20-year daily rainfall data and those calculated using 6-min pluviograph data for six representative sites.

The predicted spatial patterns of the *R*-factor and the monthly distributions across the continent with rainfall threshold $R_0 = 0$ mm are shown in Figs 5 and 6. For the northern part of the continent, the monthly distributions of *R*-factor estimated using Eqn 3 generally show peaks in the summer period from December to February. Approximately 80% of the annual rainfall erosivity occurs between December and March. A negligible fraction occurs from April to October in northern Australia. This is consistent with the common rainfall pattern in the Australia's tropics of intense storms during summer and little rainfall during winter (Rosenthal and White 1980; McIvor *et al.* 1995). For the south-eastern part of the continent, predicted monthly *R*-factor distributions change gradually from summer dominance to uniform when moving from north to south, which is comparable with continent rainfall intensity distribution (Bureau of Meteorology 1989; Yu and Rosewell 1996*a*, 1996*b*; Yu 1998). Rainfall erosivity dominates in winter in the coastal area of southwest of Western Australia. The pattern then changes to a summer dominance inland within 100 km from the coast (Fig. 5). This is also comparable with the distributions of the *R*-factor estimated using pluviograph data for the region (McFarlane *et al.* 1986).

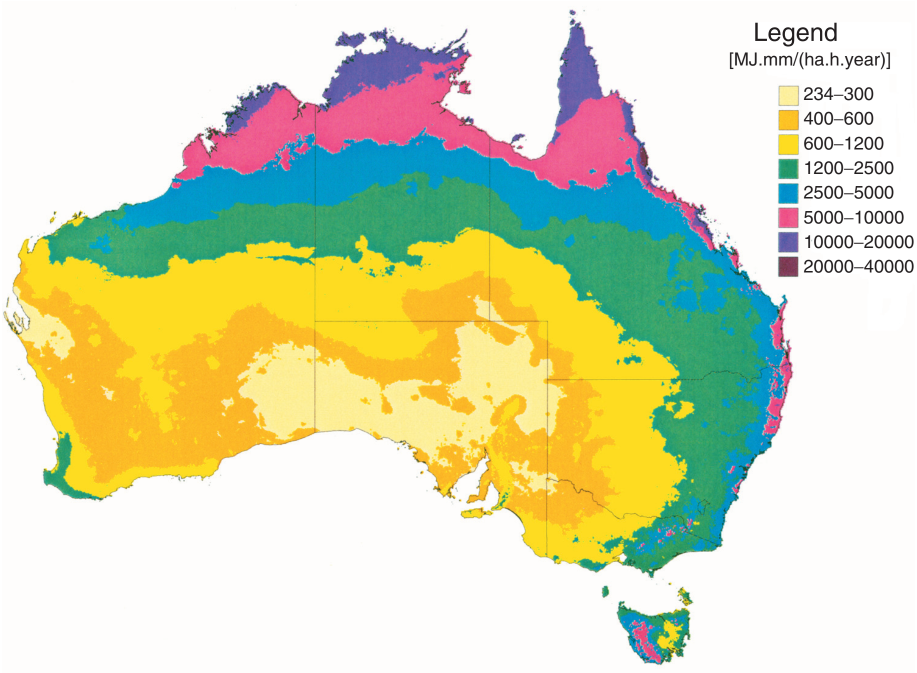

Fig. 5. Spatial distribution of rainfall erosivity at a 0.05° resolution for Australia.

The predicted *R*-factor and its seasonal distribution have been used to assess rill and sheet erosion rate at the continental scale (Lu *et al.* 2001). A digital version of the annual *R*-factor and its monthly distribution using a rainfall threshold R_0 = 12.7 mm can be obtained from the web site of the National Land and Water Resources Audit at: http://audit.ea.gov.au/ANRA/atlas/.

Conclusions

This study of spatial and seasonal distribution of rainfall erosivity in Australia and previous investigations (Yu and Rosewell 1996*a*, 1996*b*; Yu 1998) have shown conclusively that the daily rainfall erosivity model can be used to accurately predict the *R*-factor and its seasonal distribution. Despite the uncertainty of previous *R*-factor calculations using pluviograph data from different periods, the minimum value of coefficient of efficiency is 0.81 for 132 sites across Australia. The coefficient of efficiency was increased to 0.93–0.94 for the 43 sites where the long-term pluviograph data were used. The average discrepancy between calculated and predicted seasonal distribution was no more than 3%. Changing rainfall threshold from 12.7 mm to 0 mm increases the *R*-factor by no more than 5% on average. The discrepancy in the *R*-factor due to different rainfall thresholds increases as mean annual rainfall decreases. Based on the recommendations for the RUSLE and the results from this study, we would recommend the use of 0 mm as the threshold for areas with a mean annual rainfall of <400 mm. Both thresholds are suitable for other areas. The erosivity model can reproduce the effect of using different thresholds on predicted *R*-factor. In general, the predictive accuracy of the annual *R*-factor and its seasonal distributions decreases from the

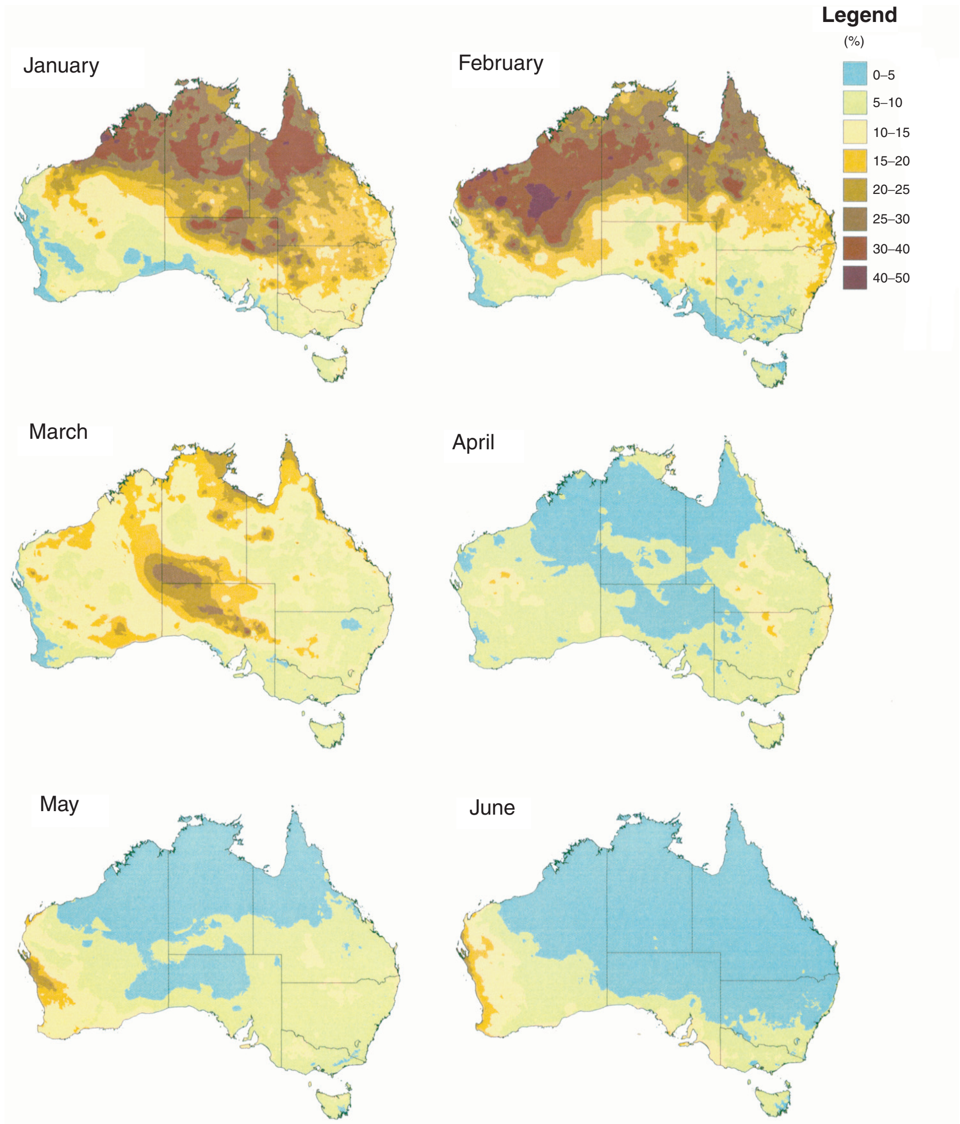

Fig. 6. Spatial patterns of monthly distribution (in percentage of annual total) of rainfall erosivity at 0.05° resolution for Australia.

tropics and subtropics, through temperate regions and winter rainfall areas, to the arid regions. Two factors contribute the low accuracy in the arid inland. One is a lack of sufficient storm events to obtain reliable long-term mean value of the *R*-factor. Another is the much coarser true spatial resolution in those areas where the number of rain gauge stations is small (Jeffrey *et al.* 2001). The high-resolution digital maps of the *R*-factor and its monthly distribution produced in this study can be used for assessing erosion hazard and determining the timing of erosion control strategies. The maps could readily be updated and

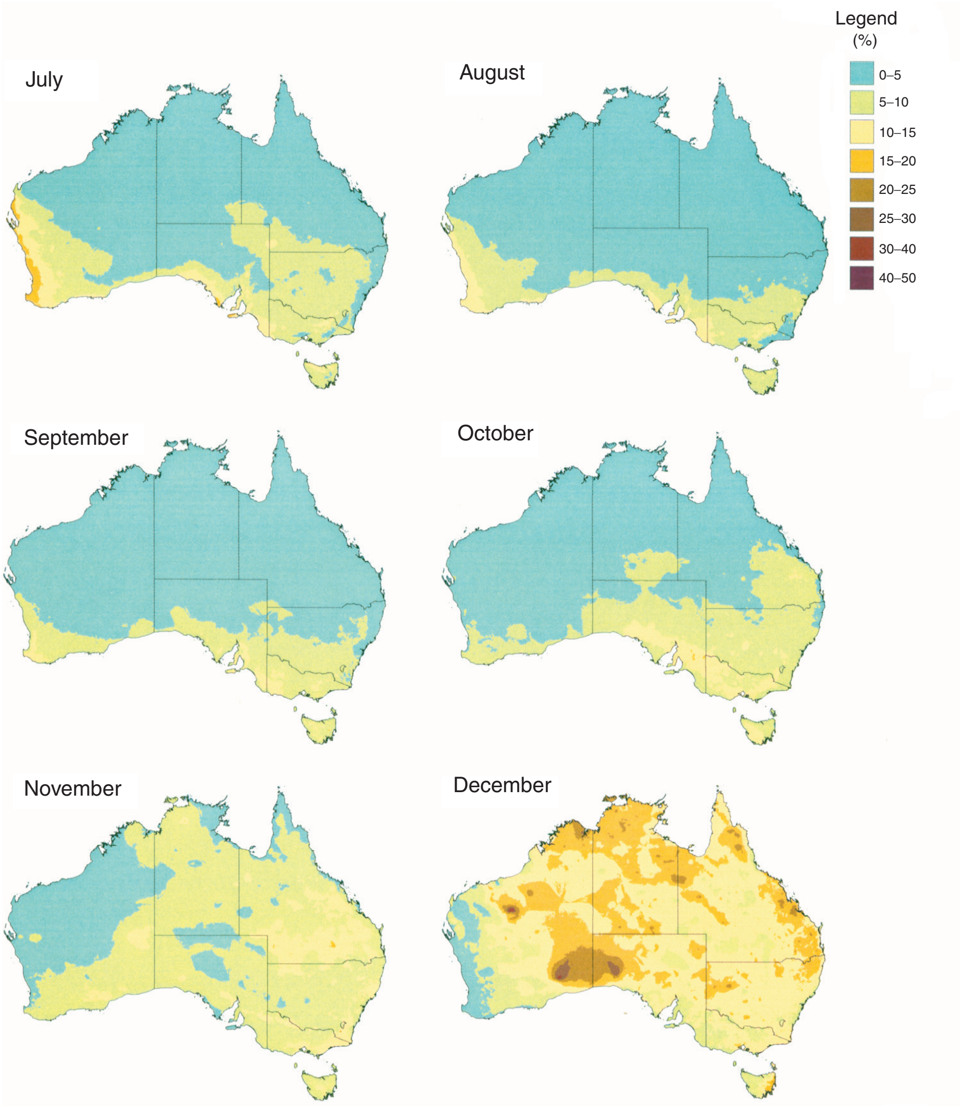

Fig. 6. (*continued*)

their quality improved as longer-term daily rainfall data become available from the Bureau of Meteorology or the Queensland Department of Natural Resources and Mines.

Acknowledgments

This work is in part funded by the National Land and Water Resources Audit (NLWRA), Australia. It contains part of the results from Theme 5.4b, sediment transport and delivery project of NLWRA led by Chris Moran and Ian Prosser at CSIRO Land and Water. We thank the Queensland Department of Natural Resources for permission to use of its interpolated daily rainfall data. Graeme Priestley is acknowledged for his GIS support in producing Figs 5 and 6.

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Manuscript received 19 December 2001, accepted 28 March 2002