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Deriving RUSLE cover factor from time-series fractional vegetation cover for hillslope erosion modelling in New South Wales

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Abstract. Soil loss due to water erosion, in particular hillslope erosion, can be estimated using predictive models such as the Revised Universal Soil Loss Equation (RUSLE). One of the important and dynamic elements in the RUSLE model is the cover and management factor (*C-factor*), which represents effects of vegetation canopy and ground cover in reducing soil loss. This study explores the potential for using fractional vegetation cover, rather than traditional green vegetation indices (e.g. NDVI), to estimate *C-factor* and consequently hillslope erosion hazard across New South Wales (NSW), Australia. Values of the *C-factor* were estimated from the emerging time-series fractional cover products derived from Moderate Resolution Imaging Spectroradiometer (MODIS). Time-series *C-factor* and hillslope erosion maps were produced for NSW on monthly and annual bases for a 13-year period from 2000 to 2012 using automated scripts in a geographic information system. The estimated *C-factor* time-series values were compared with previous study and field measurements in NSW revealing good consistency in both spatial and temporal contexts. Using these time-series maps, the relationship was analysed between ground cover and hillslope erosion and their temporal variation across NSW. Outcomes from this time-series study are being used to assess hillslope erosion hazard, sediment and water quality (particularly after severe bushfires) across NSW at local, catchment and regional scales.

Additional keywords: cover and management factor, fractional vegetation cover, GIS, hillslope erosion, MODIS, RUSLE.

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Introduction

Soil erosion by water is a natural process whereby soil particles are detached from the soil surface and transported by the movement of water. The three dominant processes of water erosion in Australia are classified as hillslope, gully and stream bank erosion (Thorman 2007). Hillslope erosion (sheet and rill erosion) is the major form of water erosion in the Australian landscape (Thorman 2007; Hairsine *et al*. 2009) that reduces land productivity, as it removes fertile topsoil containing most of the soil's plant nutrients as well as soil microorganisms that contribute to soil health (Silburn *et al*. 2011). Hillslope erosion is also a major contributor to sedimentation and degradation of water quality in rivers, lakes and reservoirs (Sekhar and Rao 2002; Wilkinson *et al*. 2009), and it could contribute ~58% to catchment fine-sediment loads (Bartley *et al*. 2007).

Hillslope erosion modelling is important in natural resource planning and in soil and water conservation, particularly in the recent climate change adaptation programs. In New South Wales, hillslope erosion information has been used routinely in land-use planning, water-quality monitoring, catchment action plans, and bushfire risk-reduction and impact assessment. For example, erosion rate has been used to help assess the relative degree of constraints for various land-use purposes in the Comprehensive Coastal Assessment (Yang *et al*. 2007; Gray *et al*. 2011) and bushfire risk assessment (Yang *et al*. 2011).

The Universal Soil Loss Equation (USLE; Wischmeier and Smith 1978) model and its derivative, the Revised Universal Soil Loss Equation (RUSLE; Renard *et al*. 1997) are commonly used throughout the world to calculate average annual soil loss per unit land area. Traditionally, the USLE/RUSLE has been used for soil conservation purposes at paddock scale, but gradually gained acceptance in broad-scale applications. Increasingly, RUSLE is also being applied to a wide variety of non-agricultural land-use conditions, including disturbed forest lands, landfills, construction sites, mining sites, reclaimed lands and military training lands (Troy *et al*. 1999; Lu *et al*. 2003, 2004).

When using the USLE/RUSLE, the component factors relating to rainfall erosivity [*R-factor*, (MJ.mm)/(ha.h.year)], topographic (*LS* factor, dimensionless), soil erodibility [*K* factor, (t.h)/(MJ.mm)], ground cover (*C-factor*, dimensionless) and soil conservation practices (*P* factor, dimensionless) are multiplied to calculate the average annual soil loss per unit area ($A = R \times K \times LS \times C \times P$). The *C-factor* is the ratio of soil loss from land under specified crop or mulch conditions to the corresponding loss from continuously tilled bare soil. For land uses except cropping lands, the *C-factor* is controlled mainly by vegetation cover. For cropping lands, in addition to vegetation cover, management practices are also important (Lu *et al*. 2003). From the standpoint of soil conservation planning, the *C-factor* is the most important and dynamic element of RUSLE because it measures the combined effect of all interrelated cover and management variables, whereas other factors (such as *LS* and *K*) are relatively static (Benkobi *et al*. 1994). In other words, hillslope erosion is influenced by the amount of exposed bare soil, which is often a consequence of broad-scale land management practices such as stocking rates and cropping practices interacting with seasonal conditions (Hairsine *et al*. 2009). Due to its dynamic nature, remote sensing techniques are commonly used to estimate *C-factor* values and their spatial and temporal distribution.

In general, remotely sensed data have been primarily used to determine the *C-factor* through land-cover classification (Millward and Mersey 1999; Reusing and Schneider 2000; Ma *et al*. 2003), vegetation index (VI) methods (e.g. de Asis and Omasa 2007; Smith *et al*. 2007; Puente *et al*. 2011), or a combination of both cover classification and VI (e.g. McGwire *et al*. 2000; Li *et al*. 2013). Typically, land covers are classified and assigned corresponding *C-factor* values (Folly *et al*. 1996; Paringit and Nadaoka 2003). This method, however, results in *C-factor* estimates that are homogeneous for relatively large areas and do not adequately reflect spatial variations in vegetation density within cover classes or over large geographic areas (Wang *et al*. 2002).

The vegetation index approach converts VIs to *C-factor* values using regression analysis (Lu *et al*. 2003; Lin *et al*. 2006; Smith *et al*. 2007) or an exponential function (e.g. Symeonakis and Drake 2004; de Asis and Omasa 2007). The normalised difference vegetation index (NDVI) is often used to derive *C-factor*. The linear or non-linear regression equations are constructed using correlation analysis between NDVI values obtained from remotely sensed images and corresponding *C-factor* values obtained from USLE/RUSLE guidelines (Wischmeier and Smith 1978; Renard *et al*. 1997) or look-up tables (e.g. Wang *et al*. 2002; Lin *et al*. 2006; de Asis and Omasa 2007). However, several studies reported low correlations between available empirical VIs and *C-factor* values (e.g. De Jong 1994; Puente *et al*. 2011). One reason is that the response of the VIs is focussed mainly on healthy (green) vegetation, and not on senescent (dry, brown or dead) vegetation, which can also be an important contributor to *C-factor*. Direct conversion of NDVI to *C-factor* values, without field verification, is often misleading and incorrect, as it does not precisely reflect the quantitative amount of protective cover against soil erosion (de Asis and Omasa 2007; Li *et al*. 2013).

More detailed and reliable time-series ground-cover products have become available in Australia. One of them is the national-wide, time-series vegetation fractional cover (February 2000 to current) including photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and bare soil (BS), as well as a quality indicator (FLAG) (Guerschman *et al*. 2009). These products provide more variability to *C-factor* mapping than traditional green VIs as they give estimation of the fractional abundance of ground vegetation and bare soil simultaneously in one pixel (~500 m). The time-series products have been evaluated and improved with well-supported user feedbacks and seasonal field measurements of fractional cover from 567 ground-truth sites, and the current version (V2.2) has an root mean square error (RMSE) of 14.7% for PV, 20.6% for NPV and 17% for BS (Guerschman *et al*. 2012). Further improvements are expected in the near future.

This study explores the use of the emerging time-series fractional vegetation cover products to derive long-term and up-to-date cover factor maps and hillslope erosion estimation to support soil-erosion hazard assessment and monitoring in NSW. The *C-factor* maps are compared and validated with previous study and field measurements. These modelling processes were implemented in a geographic information system (GIS) using automated scripts to produce time-series *C-factor* and hillslope erosion maps for NSW on monthly and annual basis for 13 years from 2000 to 2012. The relationship between ground cover and hillslope erosion and their seasonal variation across NSW were analysed to identify where and when the high hillslope-erosion hazard may occur and whether it can be cost-efficiently reduced. The generic approach and programs developed in this study are applicable to other areas, as fractional cover data are commonly available, and the *C-factor* maps can be readily updated when newer datasets are become available in the future.

Methods and procedures

The RUSLE uses a subfactor method to compute soil-loss ratios (*SLR*), which are the ratios of soil loss at any given time in the cover-management sequence to soil loss from the standard condition as described in Renard *et al*. (1997). The *C-factor* value is the average *SLR* weighted by the distribution of rainfall erosivity index (*EI*) or *R-factor* during the year.

In Australia, the dominant land use is livestock grazing on natural vegetation or rangelands (~60%), followed by nature conservation or other protected areas (22%). Only about 3% of Australia is used for cropping (ACLUMP 2002). For grazing lands, three major subfactors determine the effectiveness of vegetation in limiting soil erosion (Wischmeier and Smith 1978), namely the soil surface cover (*SC*), the canopy cover (*CC*) and prior land use (*PLU*) subfactors. The *SC* subfactor is related to the fractional cover of the soil surface by non-eroding material (basal area of plants, rocks, and organic litter). The *CC* subfactor is related to the fractional cover of the soil surface provided by aboveground plant biomass and the height that raindrops fall from the plant to impact with the soil surface. The residual and tillage subfactor is based on the prior land use, such as the influence of stabilising effects of root biomass, other organic matter, compaction and surface coherence (Puente *et al*. 2011). The product of all these subfactors for a given period (e.g. 1 month) is the *SLR* for that period (Rosewell 1993).

Recent Australian studies into wind erosion (e.g. Webb *et al*. 2009) use a negative exponential curve to relate ground cover to erodibility (equivalent to *C-factor*), where the erodibility increases rapidly as ground cover decreases to <70%. This effect is also marked for Australian native pastures where the ground cover is not randomly distributed (Rosewell 1993).

With reference to the previous studies (Rosewell 1993; Webb *et al*. 2009) in Australia, the monthly *C-factor* for the combined effect of randomly distributed ground cover with zero soil disturbance (or native grass and woodlands) is estimated from the following equation:

$$C_j = \exp(-0.799 - 7.74 * GC_j + 0.0449 * GC_j^2) * EI_j \quad (1)$$

where C_j is RUSLE cover and management factor in month *j* (1–12); GC_j is ground cover (0–1) in month *J* (1–12); EI_j is the percentage of the annual erosivity index (*EI*) that occurs over the month (*J*), and it is estimated as $EI_j = R_j/R$, where and R_j is the rainfall erosivity in the month and *R* is the annual *R-factor*. Note that the exponential component in Eqn 1 represents *SLR* and it is multiplied by EI_j to give an estimate of *C* value for the month (or period) as suggested by Wischmeier and Smith (1978) and applied in NSW (Rosewell 1993). The monthly and annual rainfall erosivity (R_j and *R*) between 2000 and 2013 was calculated using a daily rainfall erosivity model (Yu and Rosewell 1996; Yang *et al*. 2012) developed from observed 60-min pluviograph data in NSW. The monthly *C* values are accumulated over a year to give an annual *C-factor* for use in USLE/RUSLE or SOILOSS (Rosewell 1993):

$$C = \sum_{j=1}^{12} C_j \quad (2)$$

The ground cover is estimated as:

$$GC_j = PV_j + NPV_j \text{ or } GC_j = 1 - BS_j \quad (3)$$

where PV_j is photosynthetic vegetation (0–1) in month *j*; NPV_j is non-photosynthetic vegetation (0–1) in month *j*; and BS_j is bare soil (0–1) in month *j*. Figure 1 shows the relationship between bare soil and *C-factor* with reference of previous Australian studies (SOILOSS, Rosewell 1993; AUSLEM, Webb *et al*. 2006, 2009) and reflects the impact of ground cover on water and wind erosion or erodibility for dominant land uses.

In this study, PV_j, NPV_j and BS_j were derived from the 8-day MODIS fractional vegetation cover composites (Guerschman *et al*. 2009), and further integrated into monthly time-step (the mean value of four composites at each month) from February 2000 to December 2012 at 500-m ground resolution. The quality indicator (FLAG) was used to eliminate poor quality pixels (by assigning a Null data value of –9999). As the ground cover includes both green (PV) and non-green (NPV) vegetation, it represents the combined effects of *SC* and *CC* on soil loss.

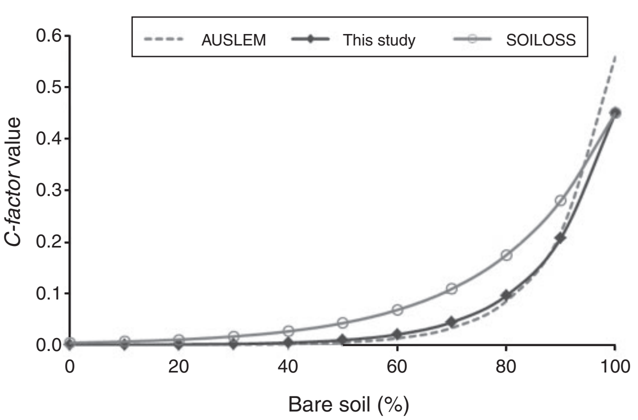

Fig. 1. Relationship between bare soil and *C-factor* for dominant land uses.

The monthly and annual *R-factor* was calculated from Bureau of Meteorology (BoM) gridded daily rainfall data using an improved a daily rainfall erosivity model for NSW (Yu and Rosewell 1996; Yang *et al*. 2012) for a continuous period from 2000 to 2012.

For comparison and gap-filling purposes, monthly *C-factor* (C_j) was also calculated from monthly NDVI ($NDVI_j$) using the same equation (Eqn 1) based on the negative relationship between BS_j and $NDVI_j$:

$$BS_j = \alpha - \beta * NDVI_j \quad (4)$$

where BS_j is the bare soil (0–1) at month *j* estimated from NDVI; $NDVI_j$ is the NDVI value at month *j*; and α and β are the regression coefficients (intercept and *x*-variable) in month *j* of a year (2000–2012). The regression relationships between BS and NDVI were calculated using 10 000 random sampling points over the whole area for each month (Table 1). Note that the sampled (10 000 points) monthly mean BS values range from 0.0023 to 0.6553, and NDVI from 0.1224 to 0.8658 (not from 0 to 1 as normally assumed).

The time-series (16-day) NDVI data were derived from the MODIS Land Products and further processed and distributed for Australian regions via CSIRO (Paget and King 2008). The monthly NDVI products from 2000 to 2012 were calculated from the 16-day NDVI time-series. Abnormal values (e.g. null or negative) were filled using neighbourhood values or adjacent images using GIS focal function. Note that the NDVI-derived *C-factor* in this study was only used for comparison and gap-filling purpose for the reason stated in the previous section. There were gaps or no-data in the fractional-cover-derived *C-factor* maps due to clouds or poor image quality. The NDVI-derived *C-factor* values were only used to fill in these gaps. The area of gaps for NSW accounts for <5% of the total area and tends to be in areas of high rainfall and high ground cover.

Table 1. Monthly regression relationship and coefficients between normalised difference vegetation index (NDVI) and fractional bare soil (BS)

BS = α – β * NDVI; α is intercept, β is *x* variable; s.d., standard deviation

Month	α	β	R^2	s.d.
January	0.61887	0.86592	0.8064	0.0745
February	0.62820	0.85184	0.8235	0.0699
March	0.62980	0.83474	0.8431	0.0642
April	0.60512	0.80673	0.8335	0.0645
May	0.58157	0.77728	0.7949	0.0683
June	0.53544	0.70927	0.7230	0.0670
July	0.57584	0.72382	0.7267	0.0730
August	0.59641	0.74999	0.7503	0.0748
September	0.62139	0.80837	0.8496	0.0618
October	0.62550	0.87637	0.8871	0.0562
November	0.62772	0.89338	0.8648	0.0623
December	0.61663	0.86433	0.8178	0.0719
Mean	0.65802	0.93258	0.8661	0.0545

Various masks have been prepared from the recent land-use mapping (1999–2009, Version 1) at NSW Office of Environment and Heritage and used in the *C-factor* mapping process to control and improve the estimation. These masks include water, urban build-up area, national parks, cropping area and snow cover. Specific *C-factor* values are used for each of these masks based on previous studies (e.g. Rosewell 1993), such as 0.0001 (lowest value) for water, 0.0039 for urban build-up area, and 0.01 for snow cover.

After calculating *C-factor* and other factors, monthly and annual hillslope erosion was computed for all NSW from 2000 to 2012 on a catchment basis at a cell size of 30 m (same as the *LS-factor*), but re-sampled to 100 m for NSW (to allow efficient process and storage for such a large area). The entire procedure for *C-factor* and hillslope erosion modelling is presented in Fig. 2; detailed methods for other RUSLE factors (*R*, *LS* and *K*) are presented or to be presented in separate papers (e.g. Yang *et al*. 2011; Yang *et al*. 2012; Yang and Yu 2014).

Automated GIS (ESRI ArcInfo) scripts (in Arc Macro Language) were developed to process the fractional cover and NDVI data and to produce time-series *C-factor* and hillslope erosion (monthly and annual) for NSW from February 2000 to December 2012. The GIS scripts enable the entire process be automatic, fast and repeatable.

Model performance, and hence its predictive capacity, is measured by the coefficient of efficiency (E_c, Nash and Sutcliffe 1970):

$$E_c = 1 - \sum_{i=1}^{M} (y_i - \hat{y}_i)^2 / \sum_{i=1}^{M} (y_i - \bar{y})^2 \qquad (5)$$

where y_i and $\hat{y}_i$ are observed and modelled values, respectively; $\bar{y}$ is the average of observed values; and M is sample size. Essentially, E_c is an indicator of how close the scatters of predicted *v.* actual values are to the 1 : 1 line, which can be considered as a measure of model efficiency for any other types of models. We chose E_c as it is commonly used to assess model performance in hydrology, soil sciences and the related studies (Yu and Rosewell 1996; Yang *et al*. 2012; Yang and Yu 2014).

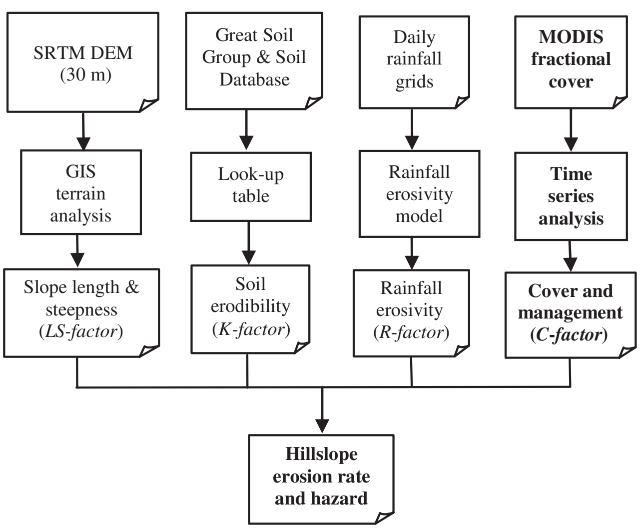

Fig. 2. Procedures for deriving RUSLE cover factor (shaded area) and hillslope erosion modelling in NSW.

Results and discussion

Time-series *C-factor* values have been derived and mapped from the recent fractional vegetation cover products for the whole of NSW on monthly and annual bases from February 2000 to December 2012. The estimated mean annual *C-factor* values in NSW range from 0.0001 to 0.4498 with a mean value of 0.0439. Relatively low values are along the eastern coast (or vegetated areas) and higher values in the western desert areas where there are more bare soils. Note that the minimum *C-factor* value was set to 0.0001 according to SOILOSS (Rosewell 1993) rather than zero as presented in previous studies (e.g. Lu *et al*. 2003).

The mean annual *C-factor* map (2000–2012) derived from recent fractional vegetation cover products in this study shows similar patterns in general compared with the previous study at CSIRO (Lu *et al*. 2003), the only existing *C-factor* map cover of NSW before this study. However, the fractional-cover-derived *C-factor* map reveals far more details and spatial variation, particularly in the drier western part of the state (Fig. 3). This may be largely due to improvement of spatial resolution (500 m)

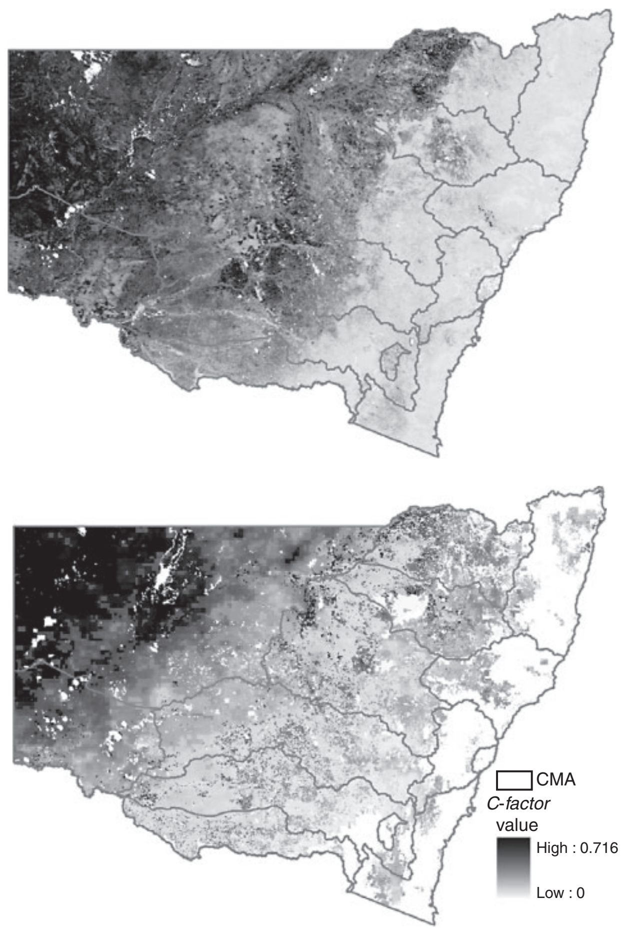

Fig. 3. Comparisons of mean annual *C-factor* derived from recent fractional vegetation cover (top) and that derived from NDVI in the previous study (bottom) (Lu *et al*. 2003).

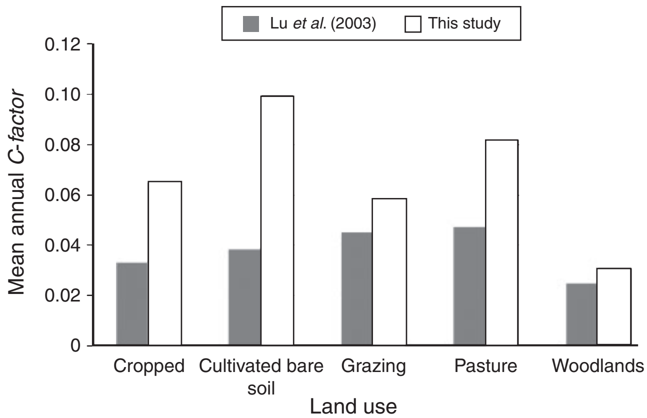

Fig. 4. Comparisons of mean annual *C-factor* based on major land-use groups.

in the recent fractional cover products compared with those used in the previous study (Pathfinder GAC 8 km AVHRR 10-day maximum composite NDVI for the period 1981–94) (Lu *et al*. 2003). The *C-factor* values derived from the fractional cover in this study also show greater variation among different land-use groups (Fig. 4) compared with the previous study (Lu *et al*. 2003), which is more consistent with what is suggested for NSW in the literature (Rosewell 1993).

There are 13 catchment management authorities (CMAs) or natural resource management (NRM) regions in NSW. This study shows great spatial variation of *C-factor* in NSW CMAs and in the Australian Capital Territory (ACT). Most eastern CMAs have a mean *C-factor* value ~0.03, 0.01 for coastal CMAs and 0.05 for western CMAs. The mean *C-factor* values based on CMAs are presented in Fig. 5. There is snow cover in winter (mostly June–August) at high altitudes in the Snowy Mountains (southern NSW). The snow effect on *C-factor* is adjusted by using a snow cover mask for winter months (a *C-factor* value of 0.01 was given). The Sydney Metropolitan CMA (which accounts for ~2.5% of the total NSW area) is excluded in this Figure (Fig. 5).

There are also strong seasonal and annual variations of the cover factor across NSW. The monthly *C-factor* maps reveal higher *C-factor* values in summer months (November–February) and lower values in winter months (May–September), which agrees with the previous study (Lu *et al*. 2003). The dynamic *C-factor* and *R-factor* were used to calculated hillslope erosion by multiplying them with the static factors (*LS* and *K*) at monthly and annual bases. Figure 6 shows the variation and impacts of the dynamic *C-factor*s on monthly hillslope erosion, and Fig. 7 shows the annual variation.

This study shows that ground cover plays important role in reducing soil loss. The monthly soil loss on bare ground (Ero_bare) is ~86 times greater, on average, than on ground with good vegetation cover (Ero_cover). The 'Reduction' column in Table 2 shows the factor of protection against hillslope erosion that ground cover provided (calculated as Ero_bare/Ero_cover). An interpretation from Table 2 is that it is more important to maintain good ground cover in summer (in particular November–February) than during winter, as rainfall erosivity (*R-factor*) is higher in summer.

Table 3 shows the impacts of ground cover (*C-factor*) on annual hillslope erosion in NSW. It summarises the annual changes of rainfall (mm), *R-factor* [(MJ.mm)/(ha.h.year)], *C-factor*, bare ground erosion (Ero_bare, t/ha.year) and erosion with current cover (Ero_cover, t/ha.year).

Among the RUSLE factors, the *C* and *R factor*s change seasonally, whereas other factors such as *LS* and *K* factors are relatively static. Hillslope erosion in NSW follows the seasonal changes in ground cover and the rainfall erosivity. This study reveals that there is more variation in *R-factor* than *C-factor*, and the monthly distribution of *R-factor* shows closer relationship with hillslope erosion in NSW. This suggests that rainfall erosivity (or rainfall amount and intensity) has more impact on seasonality of hillslope erosion than cover factor at a broader scale. A similar pattern also exists in the annual hillslope erosion variation and the impacts of annual *C* and *R* factors. Details of *R-factor* and its impact on hillslope erosion are presented in Yang *et al*. (2012).

The coefficient of efficiency (E_c) was used to measure the model performance. The reference *C-factor* values were derived

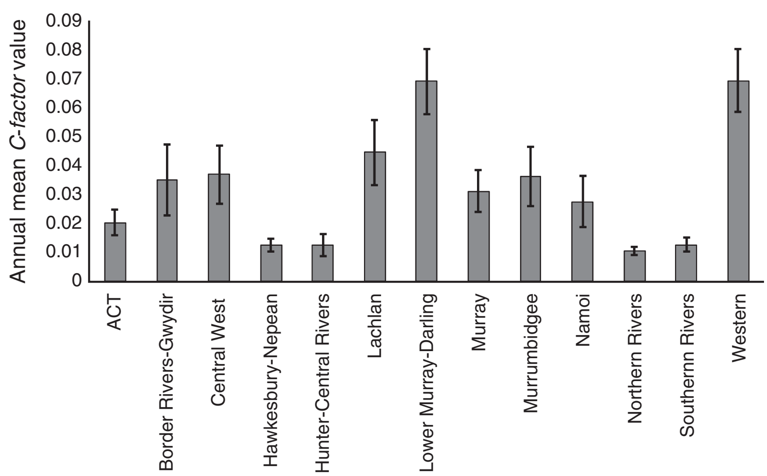

Fig. 5. Mean *C-factor* values and standard variation at NSW catchments and in the ACT.

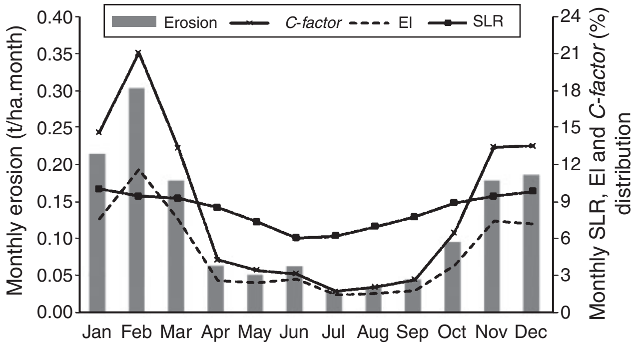

Fig. 6. Seasonal variations of *C-factor* in NSW and its relationship with hillslope erosion. EI, Percentage distribution of monthly rainfall erosivity index; SLR, monthly soil loss ratio.

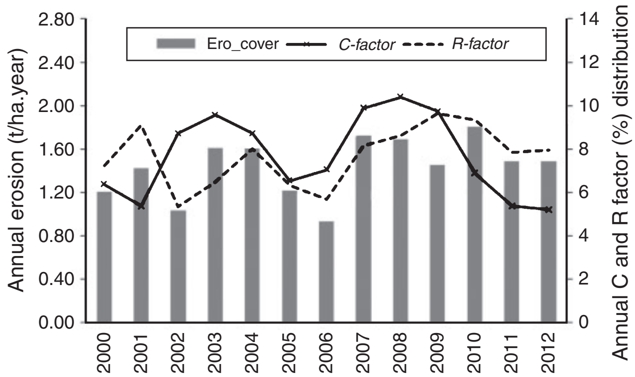

Fig. 7. Annual variations of *C-factor* in NSW and its relationship with hillslope erosion for the period 2000–2012.

Table 2. Impacts of ground cover (*C-factor*) on monthly hillslope erosion in NSW

Rainfall, Mean rainfall (mm/month); *R-factor*, rainfall erosivity [(MJ.mm)/(ha.h.month)]; SLR, soil-loss ratios; EI, rainfall erosivity index; *C-factor*, cover factor; Ero_cover, hillslope erosion (t/ha.month) with ground cover; Ero_bare, hillslope erosion (t/ha.month) on bare ground; Reduction, Ero_bare/Ero_cover, indicating ground cover protection or impact on soil loss (higher value indicating more impact)

Month	Rainfall	*R-factor*	SLR	EI	*C-factor*	Ero_cover	Ero_bare	Reduction
Jan.	67	156	0.053	0.132	0.007	0.21	15.70	73
Feb.	94	238	0.050	0.201	0.010	0.30	23.95	79
Mar.	76	154	0.049	0.130	0.006	0.18	16.70	94
Apr.	50	54	0.045	0.046	0.002	0.06	5.80	92
May	46	50	0.039	0.042	0.002	0.05	5.10	104
June	59	56	0.032	0.047	0.002	0.06	6.18	100
July	43	30	0.033	0.025	0.001	0.03	2.38	88
Aug.	42	32	0.037	0.027	0.001	0.04	3.46	89
Sept.	42	37	0.041	0.031	0.001	0.04	3.55	85
Oct.	62	78	0.047	0.066	0.003	0.10	7.78	82
Nov.	92	152	0.050	0.128	0.006	0.18	13.88	78
Dec.	78	147	0.052	0.124	0.006	0.19	13.42	72

Table 3. Impacts of ground cover (C-factor) on annual hillslope erosion in NSW

Rainfall, Mean rainfall (mm/year); *R-factor*, rainfall erosivity [(MJ.mm)/(ha.h.year)]; *C-factor*, cover factor; Ero_cover, hillslope erosion (t/ha.year) with ground cover; Ero_bare, hillslope erosion (t/ha.year) on bare ground; Reduction, Ero_bare/Ero_cover, indicating ground cover protection or impact on soil loss (higher value indicating more impact)

Year	Rainfall	*R-factor*	*C-factor*	Ero_cover	Ero_bare	Reduction
2000	825	1925	0.038	1.20	98.90	83
2001	784	2420	0.032	1.42	157.10	111
2002	540	1422	0.052	1.03	78.88	77
2003	747	1728	0.057	1.60	75.40	47
2004	750	2135	0.052	1.61	123.67	77
2005	755	1682	0.039	1.21	101.73	84
2006	617	1518	0.042	0.93	83.06	89
2007	884	2172	0.059	1.73	125.09	73
2008	850	2300	0.062	1.69	122.82	73
2009	817	2568	0.058	1.45	133.53	92
2010	1036	2489	0.041	1.80	144.86	80
2011	924	2088	0.032	1.49	136.31	92
2012	233	2118	0.031	1.49	131.69	89

from the available plot-based measurements in NSW (Edwards 1987; Rosewell 1993) and the literature as summarised in Lu *et al*. (2003) with 38 sites in total across NSW. The overall E_c calculated from the reference data and the model reached 0.649, with an over bias of 1.15 (indicating overestimate) and RMSE of 23.7%. Note that these plots experiments were conducted continuously for ~30 years but stopped around 1990 (Edwards 1987; Rosewell 1993). The treatments of these plots contain various plant types and rotations under the same soil conditions. As these plot data are the most comprehensive and longest field measurements in NSW, they are still useful as guidelines in soil erosion studies.

In addition to the field plot data, the recent road-side survey (RoS) data (2003–12) were also used for cross-validation of the modelled cover factor. The RoS is a rapid assessment method that was identified in the national review on erosion monitoring (Leys *et al*. 2009) as a way of obtaining soil erosion status, ground cover type, and cover level and management practice data. The RoS started in 2003 along 1500 km of transect across western NSW (Lachlan catchment), and 241 sites are surveyed twice a year with observations of groundcover, wind and water

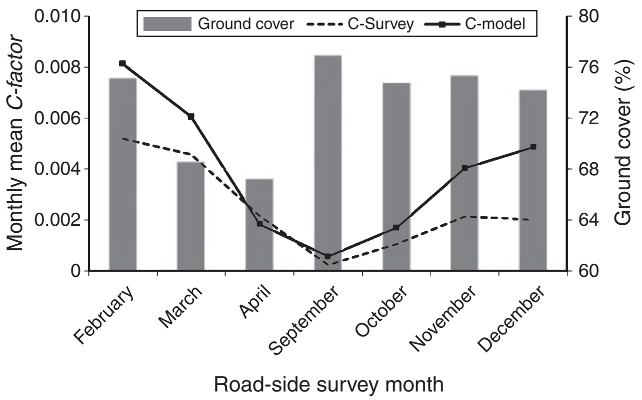

Fig. 8. Comparison of the monthly mean *C-factor* between the model (C-model) and that derived from the roadside survey (C-Survey). Note: there are no roadside survey data for January, May–August.

erosion, land use and land management practice. More than 15 000 RoS observations on ground cover were used to derived *C-factor* and compare with that derived from the fractional cover. There is good agreement between the mean monthly *C-factor* values from the model (C-model) and that derived from the RoS (C-Survey) as shown in Fig. 8.

The calculation for *C-factor* and hillslope erosion was based on the most recent datasets and the RUSLE guidelines (Renard *et al*. 1997), and is thus consistent and up-to-date. However, the outputs should be considered as relative values as there are inadequate field data available for validation across NSW. The current results show the relative spatial and temporal variation of the *C-factor* and hillslope erosion hazard, which are still useful for identification of areas that need rehabilitation for soil conservation purposes.

Conclusion and further studies

In this work we explored the use of emerging fractional vegetation cover, rather than traditional green vegetation indices (such as NDVI), to estimate *C-factor* and consequently hillslope erosion hazard across NSW. Though the method developed for estimating *C-factor* in this study is best suited for NSW rangeland condition, it has the potential to be applied to anywhere in Australia and other areas, as time-series fractional cover data are available globally.

This study found that the *C-factor* value could be determined as a function of fractional bare soil and ground cover derived from MODIS data at regional or catchment scale. The method offers a meaningful estimate of the *C-factor*, indicating ground-cover impacts on soil loss and erosion hazard areas, and is better than the commonly used method based only on green vegetation (e.g. NDVI). The continuous *C-factor* and hillslope erosion maps are significant results for watershed prioritisation and soil conservation planning, as they can be used to identify areas where soil loss from hillslope erosion could be cost-efficiently reduced (e.g. Hairsine *et al*. 2009).

The RUSLE model and *C-factor* sub-model were applied to estimate soil loss in all CMAs across NSW and implemented in GIS using automated scripts. RUSLE modelling, when appropriately used, provides meaningful information on relative hillslope erosion hazard. The outputs are available for use in many applications where land management activities are required over extensive areas, for example bushfire risk reduction, and sediment and non-point source pollution assessment. Vegetation patches have key roles in stabilising soil surfaces against both water and wind erosion. The use of time-series modelling to calculate probabilities of risks of exceeding important soil-loss thresholds promises to be an important tool for developing grazing strategies and land use policies.

In summary, this study provides an appropriate approach for estimating *C-factor* in hillslope erosion modelling in NSW, Australia, using emerging fractional vegetation cover products. This is a simple and effective way to map the spatial and temporal distribution of RUSLE cover factor and hillslope erosion hazard in a large area. The methods and results described in this article are valuable for understanding the spatial and temporal dynamics of hillslope erosion and ground cover. The study has proven that the time-series fractional vegetation cover products are useful for mapping the cover factor and hillslope erosion. These maps in turn provide baseline information for hillslope-erosion hazard assessment, and sediment and water quality modelling across NSW at local and regional scales.

In our further studies, along with the development and improvement of the fractional cover products, specific models are to be developed to obtain more accurate estimate of cover factor for all land-use conditions and practices. A separate mask of stone cover, once available, needs to be incorporated into the *C-factor* modelling to adjust the corresponding *C-factor* value for stony or rocky surfaces. More field data and further soil-loss plot trials are to be collected to assess the accuracy of the products. Cover factor and its impact on hillslope erosion are to be linked with land-management practices to help to develop the best land-use management practices.

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