VEGETATION CANOPY CHANGES AND USE OF SOILGRIDS DATA FOR ASSESSING THE EFFECT OF EXTREME RAINS ON ANNUAL SOIL LOSSES

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ABSTRACT

Extreme rains can trigger natural hazard processes such as soil erosion, land sliding and flash floods. Climate change studies show that the frequency of extreme rains is in an increasing trend, resulting in the amplification of hazard processes. For assessing the magnitude of soil losses various models are available. While annual empirical models (e.g. USLE, RUSLE, MMF) are easy to use, they do not take into account the effect of extreme rains. The event based models (e.g. LISEM, WEPP) can simulate erosion processes in detail, but rainfall event data is simply not available everywhere. To solve this problem, Shrestha and Jetten, (2018) have developed a daily erosion model and demonstrated that the effect of extreme rains can be incorporated easily in annual estimates. For running the model, daily rainfall, vegetation canopy changes, topography and soil data are required. Daily vegetation canopy changes mapping is a challenge and soil data may not be available easily everywhere due to higher cost involved in soil survey. Recently, time series NDVI and SoilGrids data are available freely, solving data scarcity problem. But, we do not know how good is the data for hazard assessment. The objectives of the study are in assessing the effect of daily canopy cover changes on rain interception, and in the use of SoilGrids data for erosion estimation. The study area is located in Sehoul, Morocco. Time series NDVI data at 1 Km resolution was obtained from Vito, Belgium (http://free.vgt.vito.be), and resampled to 15 m and at daily time step. Similarly, SoilGrids data at 250 m resolution was downloaded from ISRIC, The Netherlands (https://soilgrids.org). Pedotransfer functions were used to generate soil parameters and the daily erosion model was applied to assess soil losses. The results show that vegetation canopy cover plays an important role in the magnitude of soil losses. Canopy cover intercepts rain and protects the soil from raindrop impact. When canopy cover is lower, erosion rates are higher. During extreme rains, erosion can be very severe. The study shows that SoilGrids is a useful data source, and can be applied in daily erosion assessment in the semi-arid environment. The results also show that daily erosion modelling gives better picture of annual soil losses since the effects of extreme rains are also incorporated.

1. INTRODUCTION

Soil erosion is a wide spread problem occurring in all the climatic regions, which is responsible for decreased soil productivity endangering food security and causing offsite effects. Erosion rates can be alarming when excessive rain falls in a period when vegetation cover is lower (Vrieling et al., 2014). Extreme rains are often major causes of increased runoff, excessive soil losses, flash floods, and unwanted sedimentation problem in reservoirs, infrastructure and agriculture fields. Research on climate change shows the increase of the frequency of extreme rains (Board on Atmospheric Sciences and Climate, 2016), which demands our attention in understanding the associated problem so that preparations can be made in time in reducing the damage. For this, it becomes necessary to make first an assessment of the magnitude of erosion problem caused by extreme rains.

Various empirical models are available to assess soil losses e.g. RUSLE (Renard et al., 1991), MMF (Morgan, 2001), SLEMSA (Stocking, 1981) and SWAT (Gassman et al., 2007), but they are not capable of assessing the effects of extreme rains. Since the annual models use the average yearly rain and vegetation cover estimates, they ignore the effects of extreme rains. The event based models simulate soil detachment and transportation during a storm event e.g. LISEM (Jetten, 2002)(De Roo, 1996), WEPP (Laflen et al., 1991), EUROSEM (Morgan, et al., 1998), but detail rainfall data is almost impossible to get to run these models. Fortunately, assessing the effects of extreme rains is now possible using the recently available daily erosion model (Shrestha and Jetten, 2018).

The daily erosion model assesses rain interception loss to estimate effective rain for calculating soil losses. For this, it is necessary to map land cover and model vegetation canopy cover changes on a daily basis. The availability of time series NDVI data such as SPOT GVT and MODIS NDVI allow us to have temporal changes in vegetation cover.

Similarly, the daily erosion model estimates soil detachment by raindrop impact as well as by surface runoff. Surface runoff, estimated from soil water balance, is used for the transportation of detached soil particles. Soil parameters such as particle size distribution, water holding capacity of soil, hydraulic conductivity and porosity are required in modelling water fluxes in the soil. But, detail soil data is often not available easily because of high costs involved making surveys. Recently, 250m SoilGrids data, based on global interpolation and machine learning techniques on 150,000 soil profiles data collected worldwide, is available freely (Hengl et al., 2017). The SoilGrids data solves the soil data scarcity problem but its usefulness and application on erosion modelling has not been yet done. The objective of the research is on using time series NDVI data for assessing daily rain interception and the usefulness of SoilGrids data for assessing the effects of extreme rain. It is applied in a case study in Sehoul commune in Morocco.

2. STUDY AREA

The study area is located in between 6° 34’ and 6°46’ W longitudes, 33° 52’ and 33° 59’ N latitudes, covering approx. 96 sq.km and about 20 km east of Rabat in Morocco (Figure. 1). Elevation varies from 45 to 233 m asl. The area receives in average 540 mm rain (Rabat/Sale meteorological station) calculated over a 59 year period (1951-2010). There is inter-annual variation of precipitation with some years receiving below average rains causing extended drought while some years receive above average rains. The river Bou Regreg drains the area. The main land cover/land use types are cork oak forest, plantation forest, rainfed agriculture, and grazing land. Grazing takes place in the cork forest since it is not protected. Insufficient precipitation has been the common problem for cultivation. Low vegetation cover and intense rain results in excessive soil losses. Extensive gully formation occurs not only in grazing land but also in the forest (DESIRE, 2013). When gully formation is severe, cultivation is not economical and the land is often abandoned making the situation very severe.

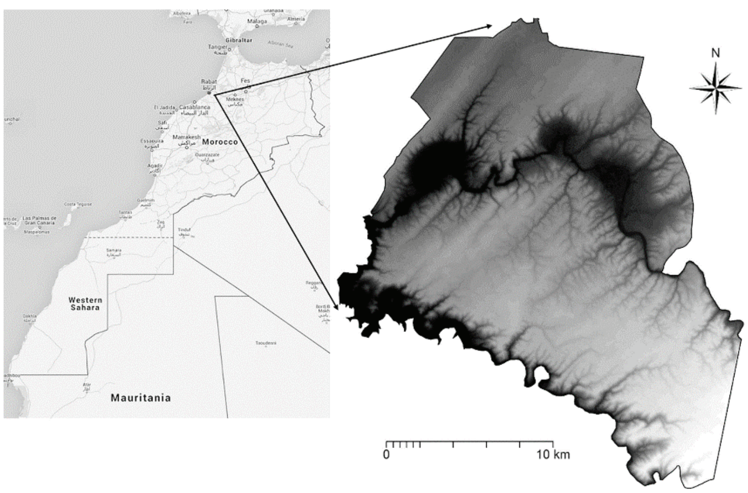

Figure 1. Study area

3. MATERIALS AND METHODS

3.1 Generation of land cover map

Aster multi-spectral data (ASTL1 B data), acquired on 14 July 2003 at spatial resolution of 15 m, was obtained. The data was pre-processed for atmospheric correction before running maximum likelihood classifier. Sufficient points were collected to be used as training samples for classification as well as for accuracy assessment.

3.2 Generation of daily canopy cover maps

For erosion studies it is essential to estimate rain interception by vegetation canopy. The effective rain for splash detachment and for runoff estimation is total rain minus rain interception. Interception storage is estimated by computing leaf area index (LAI) which depends on vegetation type and is generally derived from canopy cover. SPOT VGT images at 1 km spatial and 10 days resolutions, consisting of total 38 images were obtained from Flemish Institute for Technonogical Research, Belgium (http://free.vgt.vito.be). The images were resampled to spatial resolution of 15m. The obtained time series SPOT VGT data were transferred to NDVI values ranging from -1 to 1 to make it easier to interpret as follows:

$$NDVI = DN * 0.004 - 0.1 \quad (1)$$

From the obtained time series data, linear interpolation was carried out to obtain daily NDVI images as follows:

$$y = y_1 + \frac{x - x_1}{x_2 - x_1}(y_2 - y_1) \quad (2)$$

Where, y is pixel value at location x, between two values y1 and y2 at positons x1 and x2. The x1 and x2 are the NDVI images on 2 dates (day number in the year) and y1 and y2 are the corresponding NDVI values. From the NDVI the vegetation cover factor is generated using the exponential function (Van der Knijff et al., 1999) as follows:

$$Cover = 1 - e^{-\alpha \frac{(NDVI)}{(\beta - NDVI)}} \quad (3)$$

Suggested values for the constants α, β are 2 and 1.

3.3 SoilGrids data and pedotransfer functions

SoilGrids data layers of particle size distribution (sand, silt and clay percentages), organic matter content, coarse fragments and bulk density of topsoil (15 cm) were downloaded from ISRIC, The Netherlands (https://soilgrids.org). The obtaianed data in 250 m resolution was resampled to 15 m. Pedotransfer functions were used to generate soil parameters required to run the daily erosion model. The parameters are saturated hydraulic conductivity (mm/hr), field capacity and wilting point according to (Saxton and Rawls, 2006), soil porosity using bulk density and particle density and soil erodibility factor based on (Wischmeier and Smith, 1960). Soil cohesion was estimated based on clay content, which is adapted from (Morgan, 2001). The codes for pedotransfer functions, written in PCRaster, were then applied to SoilGrids data.

3.4 Topographic data

For topographic data analysis, SRTM DEM at 30 m resolution obtained from US Geological Survey's EROS data center (https://earthexplorer.usgs.gov) was resampled to 15 m resolution. From this, slope gradient map was generated which was used in the estimation of transport capacity of overland flow, and flow network (Figure. 2) used in routing surface runoff. The flow network was generated using the direction of maximum slope gradient in a grid cell.

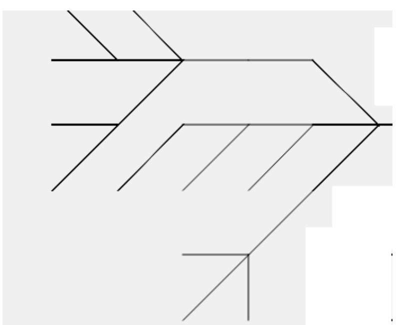

Figure 2. Generation of flow network for routing surface runoff based on maximum slope direction in a grid cell.

3.5 Daily erosion modelling

The daily erosion model estimates rain interception as well as soil water balance on a daily basis. Soil detachment and runoff estimation is based on effective rain (daily rain minus canopy interception) multiplied by a runoff fraction, which is based on soil water balance. Detail description of the model can be found at (Shrestha and Jetten, 2018). It is outside the scope of this paper to describe in detail how the daily erosion model works. The model codes were written in PCRaster, an open source GIS software for environmental modelling (http://pcraster.geo.uu.nl). The parameters required to run the model are: daily rainfall (mm), daily vegetation canopy cover (in percentage), soil parameters (soil porosity in percentage, saturated hydraulic conductivity in mm/hr, soil erodibility factor in 0 to 1, cohesion in kPa) and topography (slope gradient in percentage, flow network). Detail model parameters are given in Table 1. The model gives results on daily soil detachment, erosion and deposition (t/ha). The daily erosion estimates are added together to get annual soil loss. The results can be assessed per land cover/land use type. The daily erosion model was run twice: using SoilGrids data and using soil data collected from the field. In addition, the model was also run using 2 rainfall data: one from rainfall (2003) which represents long term average rain in Morocco, and one from the year with extreme rainy days (1975).

Table 1. Input parameters for the Daily erosion model

Factor	Parameter	Definition and remarks
Climate	rain	Daily rainfall (mm)
	ETo	Potential evapotranspiration on a daily basis (mm)
	I	Rainfall intensity (mm/hr: 10 for temperate climate, 25 for tropical and 30 for season climates (e.g. Monsoon or Mediterranean)
Soil	theta_s	Porosity (volumetric percentage)
	theta_fc	Field capacity (volumetric %)
	Theta_wp	Wilting point (volumetric %)
	thetainit	Initial soil moisture (volumetric percentage, e.g. 0.5 of wilting point
	coh	Cohesion (kPa)
	K	Soil erodibility factor (0-1)
	ksat	Saturated hydraulic conductivity of soil (mm/hr)
Topography	DEM	Digital elevation model
	grad	Slope gradient (%)
	ldd	Local drainage direction map
Land cover	landuse	Land cover/land use map
	NDVI	Time series NDVI maps (e.g. VGT SPOT)
	Kc	FAO crop factor
	Cover	Canopy cover (%, expressed in 0-1)
	GC	Ground cover (% expressed in 0-1)
	PH	Plant height (m)

4 RESULTS AND DISCUSSIONS

4.1 Land cover and rain interception

Land cover classification result is shown in Figure 3. Overall classification accuracy obtained is 89%. The area has dominantly cropland (3671 ha), which is followed by grazing land (2826 ha), cork forest (1818 ha), bare soil (1103 ha) and plantation forest (200 ha). In terms of obtaining time series NDVI images, it was not a problem to get cloud free images for Morocco since it is located in drier climatic region. Linear interpolation of 10 day NDVI images into daily estimates shows good response of daily rainfall to vegetation cover. Vegetation cover decreases as from March to the minimum NDVI values (less than 0.4) during July/August and it increases as from October when it starts to rain until December when it reaches maximum (NDVI value of about 0.7).

4.2. Soil loss estimates

Soil parameters for running daily erosion model were derived by applying pedotransfer functions on the SoilGrids data. The result is shown in Table 2 and in Figure 4. Highest soil losses (>50 t/ha) were recorded in the cork forest and in the grazing land, which are located in the steep slopes (>30% slopes). Because of over grazing no undergrowth of vegetation is possible in the forest areas. The reason for high soil losses in the plantation forest could be due to the young age of the trees, with low canopy cover and lower soil protection. Lower soil losses (4-6 t/ha) were recorded in the gently sloping areas for all the land cover types. Erosion assessment was also carried out using soil parameters collected in the field and from laboratory analysis of soil samples. The results show that there is not considerable variation in soil loss assessments whether field based soil data or SoilGrids data is used (Table 2). Some differences were found in plantation forest and in grazing land, especially in the steeper slopes (> 30% slopes). In general, soil losses were found to be relatively higher if SoilGrids data is used but the differences are not so big. It seems that soil loss estimation is limited by the transport capacity of the runoff water. Soil detachment can be higher but it seems that everything cannot be transported down the hill and is limited by the capacity of the runoff water. Soil erodibility factor in field based data varies from 0.1 to 0.9 whereas it varies from 0.2 to 0.4 in SoilGrids data, which means higher soil detachment rates if field data is used instead of SoilGrids data. Similarly, saturated hydraulic conductivity varies from 1.3 to 20 mm/hr for field data whereas it varies from 0.9 to 154 mm/hr in case of SoilGrids data. This shows that rain infiltration will be relatively higher in case of SoilGrids data. In both the cases runoff generation and the transportation capacity seems to be somewhat similar. Although soil detachment rate is higher transport capacity seems to be the one which determined the soil losses. This could be the main reason why soil loss estimates are similar in both cases: using fieldwork based soil data or using SoilGrids data.

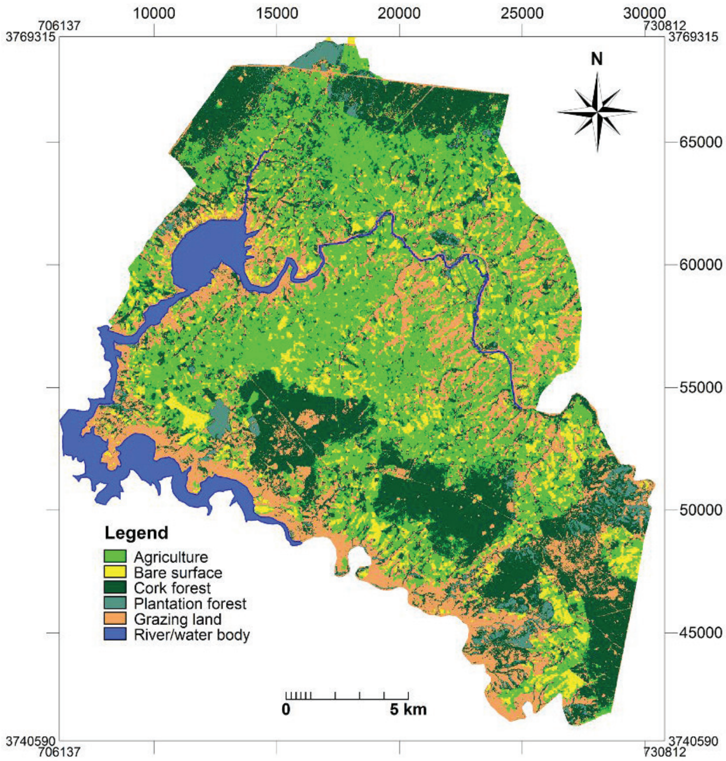

Figure 3. Land cover classification

Table 2. Soil loss assessment using field data and SoilGrids data

Land cover	Slope classes	Surface area		Soil loss assessment with field data		Soil loss assessment with SoilGrids data	
		Hectare	Percent	t.ha^{-1}	Average	t.ha^{-1}	Average
Agriculture	Level to gently sloping (0-8%)	1990	54	6		6	
	Rolling to hilly (8-30%)	1574	43	16	11	17	11
	Steeply dissected to mountainous (>30%)	107	3	31		32	
Bare soil	Level to gently sloping (0-8%)	663	60	6		6	
	Rolling to hilly (8-30%)	426	39	15	11	15	10
	Steeply dissected to mountainous (>30%)	14	1	27		26	
Cork forest	Level to gently sloping (0-8%)	1257	69	6		6	
	Rolling to hilly (8-30%)	483	27	24	14	25	14
	Steeply dissected to mountainous (>30%)	78	4	52		60	
Plantation forest	Level to gently sloping (0-8%)	143	72	4		4	
	Rolling to hilly (8-30%)	30	15	16	16	18	18
	Steeply dissected to mountainous (>30%)	27	13	34		39	
Grazing land	Level to gently sloping (0-8%)	808	29	6		5	
	Rolling to hilly (8-30%)	1512	53	22	18	24	20
	Steeply dissected to mountainous (>30%)	506	18	47		59	

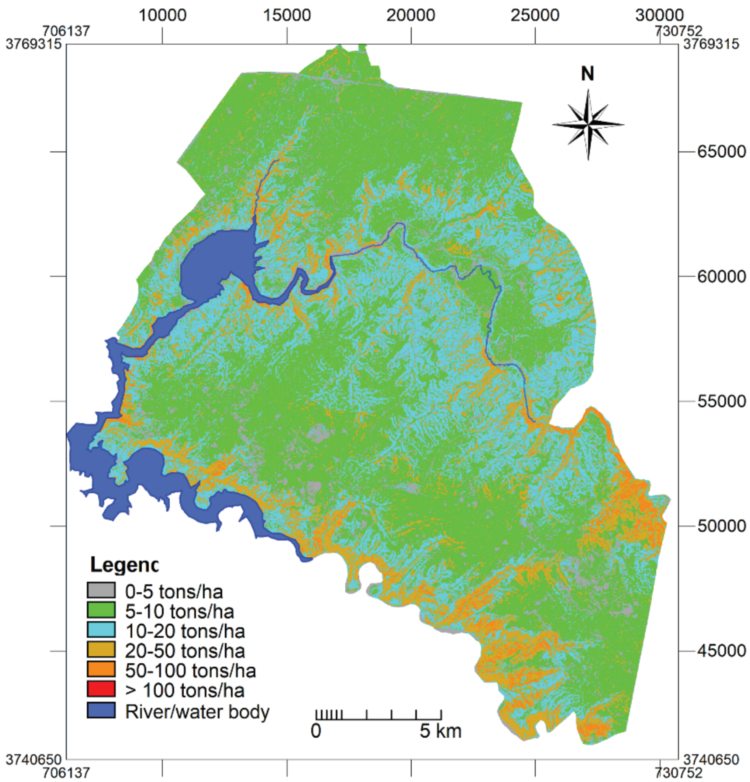

Figure 4. Soil loss assessment using SoilGrids data

The result also shows that cork forest intercepts the highest rainfall (140 mm rain which is ¼ of the annual rain) and lowest interception is by plantation forest (57 mm) (Table 3). The reason for having lower interception in plantation forest could be the young age of the plantation trees. Higher rain interception in grazing land is probably due to the presence of shrubs.

Table 3. Total interception in different land cover types in 2003

Land cover	Surface area (ha)	Total interception mm/(percent of annual rain)	Annual rain mm
Agriculture	3671	78 (0.14)	568
Bare soil	1103	71 (0.12)	568
Cork forest	1818	140 (0.25)	568
Plantation forest	200	57 ((0.10)	568
Grazing land	2826	117 (0.20)	568

The model was run again with rainfall data from 1975 to see the effect of extreme rainy days. Total rain in 2003 was 658 mm and in 1975 annual rain was 669 mm, both year receiving similar amount of rain. In 1975 there were few days with extreme rain (40 mm) with the maximum amount received in 24 hour being 149 mm on 17 Dec, which accounts for about one fifth of the annual rain (Table 4). Soil loss results also show the effect of the presence of extreme rainy days in 1975. Although annual rain in both the years can be considered similar (658 mm rain in 2003 and 669 mm rain in 1975) soil losses in 1975 are almost double in all the land cover types, which is mainly due to the presence of extreme rains (Figure. 5). In 2003 only 2 days received rain above 40 mm rain.

Table 4. Normal rain in 2003 and the year with extreme rainy days (1975)

Land cover	2003 Annual rain 658 mm (max 24 hr rain 72 mm)		1975 Annual rain 669 mm (max 24 hr rain 149 mm)	
	Soil loss annual (t/ha)	Soil loss 9 Dec 2003	Soil loss annual (t/ha)	Soil loss 17 Dec 1975
Agriculture	12	5	21	15
Bare soil	10	4	18	12
Cork forest	14	7	30	23
Plantation forest	18	8	37	28
Grazing land	20	10	47	38

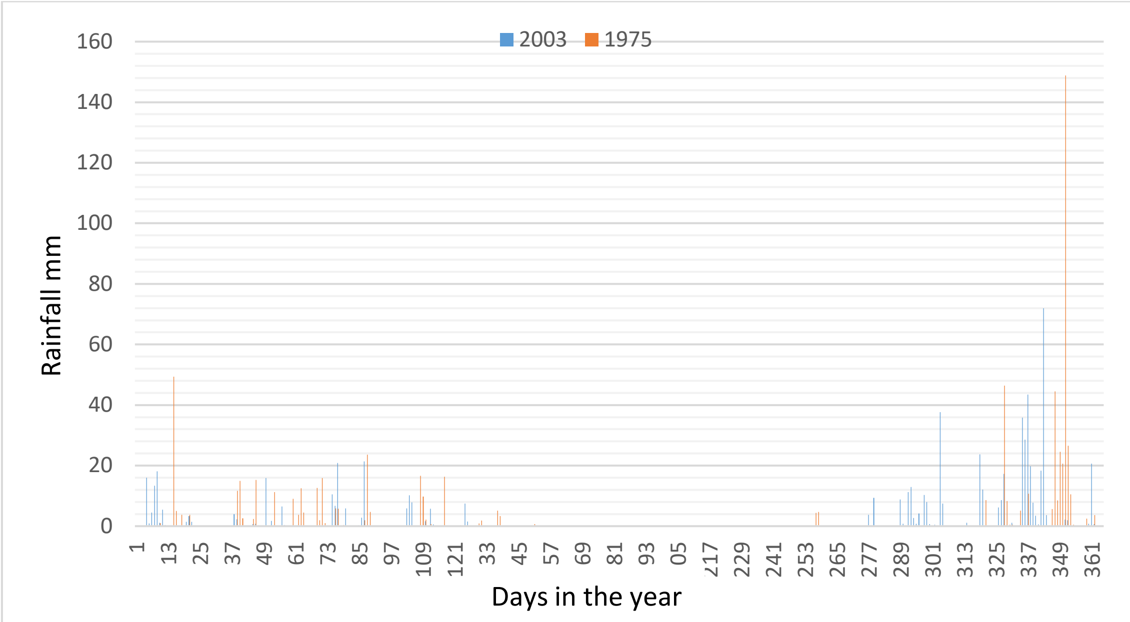

Figure 5. Rainfall patterns in Morocco: average rainfall (2003), and with extreme rains in 1975 (maximum 149 mm rain in 24 hours)

4. CONCLUSION

The result shows that rain interception can be higher in drier regions (upto 25% of the annual rain) depending on vegetation types. The maximum annul interception of 140 mm was estimated for the cork forest. This is due to the dryness of the area. The result also shows that SoilGrids data can be applied easily in erosion studies in combination with modelling vegetation canopy cover changes. It seems that soil loss is limited by the transport capacity of the runoff water in the semi-arid environment. The results also shows that daily erosion modelling gives better picture of soil losses since it also incorporates the effects of extreme rains, which is not possible by using annual erosion models. The daily erosion model can be applied using SoilGrids data in areas with similar landscape and environmental conditions like in Morocco. For application of the method in other areas, especially with different climatic conditions and in varying geomorphic setting, the method will have to be tested first.

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