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In-between forest expansion and cropland decline: A revised USLE model for soil erosion risk under land-use change in a Mediterranean region

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ABSTRACT

The present study illustrates an original approach for the long-term assessment of soil erosion risk under land-use changes in a Mediterranean region (Matera, southern Italy). The study has been focused on the implementation of a modified Universal Soil Loss Equation (USLE) model at three time points (1960, 1990, 2010) with the objective to evaluate the contribution of each component to model's performance and model outcomes' reliability. A modified USLE model was proposed for the assessment of soil erosion risk, based on the simplification of model's parameters and the use of high spatial resolution datasets. Spatio-temporal variability in the model's outcomes was analyzed for basic land-use classes. Our approach has improved model's flexibility with the use of high spatial resolution layers, producing reliable long-term estimates of soil loss for the study area.

1. Introduction

Soil erosion is a key environmental process that reflects specific soil characteristics, climate regimes, vegetation cover, and land mismanagement depending on natural and anthropogenic factors (Quinton et al., 2010). Soil erosion is mainly the result of the action of water or wind. Anthropogenic causes are linked to multiple interactions between human activities and land-use (García-Ruiz et al., 2013). In this sense, soil erosion is closely related to land-use changes as a result of urbanization, land abandonment, overgrazing, deforestation and forest fires (Grimm et al., 2002; Nunes et al., 2010, 2011; Mancino et al., 2014). At the European level about 115 million hectares of rural land are affected by soil erosion (12% of the continental surface area), with increasingly negative effects on soil productivity and on the economic sustainability of agriculture (SOER, 2010). In the Mediterranean region, soil erosion has affected stability of environmental systems and socioeconomic resilience of rural land (Conacher and Sala, 1998; Montanarella, 2007), and thus requires a thorough implementation of dedicated soil conservation strategies (Morgan, 2005; Ferrara et al., 2014). Recent studies have stressed the role of land-use changes in soil erosion dynamics in areas where changes in vegetation cover are strictly related to the quality and type of soils (Razafindrabe et al., 2010).

Soil erosion has been also related to socioeconomic processes such as the abandonment of agricultural practices in marginal areas (Koulouri and Giourga, 2007). The implementation of agro-environmental measures within the Common Agriculture Policy (CAP) has contributed to support agriculture in fertile areas, stimulating the abandonment of the traditional farming systems in less favoured areas (Caraveli, 2000; MacDonald et al., 2000). The relation between land abandonment and soil erosion has been described as a long-term pattern influenced by spatially-varying conditions related to soil type, slope, land-use and the adopted agricultural practices (Kosmas et al., 1997). Land abandonment may produce either positive or negative impacts on soil erosion depending on slope, precipitation regime and intensity regulating the superficial runoff (Liu et al., 2000; Kosmas and Gerontidis St Marathianou, 2000; Zhou and Shangguan, 2006).

Several approaches have been proposed to assess soil erosion risk. The most widely used is the Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (1978) and applied to vastly different territorial contexts characterized by specific climate regime, soil type and topography. The USLE model estimates the annual soil loss per unit area on the base of soil, vegetation and climate variables including soil erodibility, rainfall intensity, slope length and steepness, land-use and management (Renard

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et al., 1991). Vegetation, geology and land-use are key variables in the USLE model (Nasiri, 2013). Type and degree of soil cover are closely linked to the capacity of hydraulic regulation and erosion protection provided by different vegetation cover and forest types; at the same time, land-use and management play a key role in soil erosion processes. In particular, forests provide hydraulic regulation and soil protection contributing to reduce soil degradation and performing critical functions as biodiversity conservation, primary production carbon uptake and storage (Nolè et al., 2009).

In the last years a revision of the USLE model has been proposed (Renard et al., 1997; Van der Knijff et al., 2000; Nasiri, 2013) by introducing new parameters that contributed to a refined approach called RUSLE (e.g. Borrelli et al., 2016) with improved model performance. The introduction of new algorithms for the evaluation of model parameters has contributed to improve model flexibility (Panagos et al., 2015a). Further investigation is required to improve the long-term efficiency of soil loss estimates (Panagos et al., 2014, 2015b,c,d,e).

Our study introduces an original and simplified approach based on the USLE methodology (Wischmeier and Smith, 1978) for the diachronic assessment of soil erosion risk in an area of southern Italy (Matera, Basilicata) as a function of changes in the use of land (Salvati et al., 2013a; Mancino et al., 2014) driven by land management policies (Salvati and Ferrara, 2014). The proposed approach is based on a thorough implementation of three parameters in the USLE model: (i) the rainfall erosivity factor (R factor) based on average annual rainfall, (ii) the Crusting Index (CI) estimating the soil erodibility factor (K factor), and (iii) the RUSLE3D algorithm proposed by Mitasova (1996) for the evaluation of the slope length factor (LS factor). Specific tolerable erosion levels (T) for basic land-use classes were finally used to evaluate model's results.

Based on the hypothesis that forest expansion at the regional scale contributes to the mitigation of soil erosion risk and contrasts local-scale increases in the erosion rate associated to cropland abandonment and soil mismanagement, the impact of land-use dynamics on soil erosion rates was assessed with the objective to evaluate reliability of the diachronic soil erosion estimates produced by the modified USLE model. This model was applied in a dry area of southern Italy exposed to high risk of soil erosion and tested using data covering an enough long time interval (1960–2010) to assess model reliability under landscape transformations.

2. Methodology

2.1. Study area

The study area extends 3434 km^2 in the prefecture of Matera (Basilicata, southern Italy) and is administered by 31 municipalities (Fig. 1). The area is characterized by a typical Mediterranean climate with hot and dry summers and cold-rainy winters. The study area is subdivided in three main geographical districts: (i) a mountain area in the north-west part of Matera's prefecture, (ii) a hilly area in the central area and (iii) a flat area along the Ionian Sea coast, east of Matera. Clay is the main component of soils in the area, being a relevant factor of landslides (occurring especially on hilly areas dominated by blue-grey clay), in combination with place-specific morphological and structural characteristics. Arable land is the prevailing use of land especially in the eastern part of Matera's prefecture. Forests are concentrated in the western part of the area.

2.2. Assessing soil erosion risk

Soil erosion risk was assessed over five decades (1960–2010) through a modified version of the USLE model:

$$A = R * K * LS * C * P \qquad (1)$$

where: A = Mean annual soil loss (t ha^{-1} year^{-1}); R = Rainfall erosivity factor (MJ ha^{-1} mm^{-1} year^{-1}); K = Soil erodibility factor (t ha h MJ^{-1} mm^{-1}); L = Slope length factor (dimensionless); S = Slope factor (dimensionless); C=Cover management factor (dimensionless); P = erosion control practice factor (dimensionless).

Modifications to the original USLE methodology (Wischmeier and Smith, 1978) refer to the evaluation of the factors R, K and LS, as described below. Due to the lack of long-term information on precipitation erosivity, the R factor has been calculated using the equation proposed by Van der Knijff et al. (1999):

$$R = 1.3 * P_j \qquad (2)$$

where P_j represents annual precipitation (mm).

The K factor was estimated on the base of soil texture classes and organic matter content (Table 1S, Supplementary materials) as reported by Wischmeier and Smith, 1978; Cook et al. 1985; Van der Knijff et al., 1999; Stone and Hilborn, 2000; de Vente et al. 2006; Kinell, 2007. The soil erodibility factor values reported in Table 1S were modified combining K factor with the Crusting Index (CI) that describes the soil tendency to crusting as function of land-use. Soil crusting reduces water infiltration with a significant increase in surface water runoff and soil erosion risk. According to Grimm et al. (2003), the crusting factor was calculated as: CK = 0.75 K for CI = 1, CK = 0.85 K for CI = 2, CK = K for CI = 3, CK = 1.15 K for CI = 4 and finally CK = 1.25 K for CI = 5. The Slope length factor (LS) was calculated using the RUSLE3D algorithm proposed by Mitasova (1996), where LS in a certain point *r* (x, y) of the slope is calculated as:

$$LS(_r) = (m + 1)[A(_r)/\alpha_0]^m[\sin\beta_r/\beta_0]^n \qquad (3)$$

where $\alpha_0 = 22.13$ m; $\beta_0 = 5.14°$; sin $\beta_0 = 0.0896$ and A_r is upslope contributing area per unit contour width (m^2/m), β_r is the angle of the slope (deg), α_0 e β_0 are respectively the length (22.13 m) and angle (5.14 deg) of the standard soil plot used for the USLE calibration.

The exponential factors *m* and *n* are functions respectively of erosion type and land use. According to the erosion typology in the study area (sheet flow or rill flow) m and n were fixed to 0.4 and 1 respectively. The value of C for each land-use class (Table 2S, Supplementary materials) was estimated as the C average for each land-use class (Van Vliet et al., 1976; Wischmeier and Smith 1978; Dissmeyer and Foster 1980; Zachar 1982; Šúri et al., 2002; Wall et al., 2002; Lee and Lee 2006; Stumpf and Auerswald 2006; Adediji et al., 2010). The erosion control practice factor P has been considered equal to 1. According to the support practices dataset used for the assessment of soil loss by water erosion in Europe (Panagos et al., 2015d), no information on agricultural activity were available for the study area. Main modifications compared to the original USLE methodology introduced in this study are as follows: (i) the rainfall erosivity factor (R factor) evaluation was simplified using the average annual rainfall; (ii) the soil erodibility factor (K factor) estimation was refined by introducing the Crusting Index (CI); (iii) the slope length factor (LS factor) was evaluated using the RUSLE3D algorithm proposed by Mitasova (1996).

In order to evaluate soil erosion risk and potential loss in land productivity and biodiversity, the Tolerable erosion level (T) was finally analyzed for basic land-use classes. T is mainly a function of soil erosion and soil formation rates that, in turn, depend on land characteristics (McCormack et al., 1982), including land cover type and climate regime (Morgan, 2005). Morgan (2005) illustrated various methodologies to identify soil loss tolerance thresholds, ranging from 11.2 t ha^{-1} yr^{-1} (set by the Soil Survey Division Staff, 1993) to 6 t ha^{-1} yr^{-1} (set by OECD, 2001). More recently, Verheijen et al. (2009) identified a tolerable erosion level for Europe ranging from 0.3 to 1.4 t ha^{-1} yr^{-1}, according to place-specific rates of soil loss and formation. For the present study we used the methodology proposed by the Italian National Agency of Environmental

Fig. 1. Study area, Matera Prefecture (Basilicata, southern Italy).

Protection (APAT, 2004), in turn following the directives provided by the European Union Soil Thematic Strategy which define specific T values based on Corine Land Cover land use classes (Table 2).

2.3. Data analysis

A spatial information system was developed integrating land-use, climate and soil information at a detailed spatial resolution (30 m^2). Diachronic information on land-use were derived from the 1: 200.000 Land Use Map of Italy dated 1956–1960 (CNR and Directorate General of Cadastre, 1960) and two Corine Land Cover 1: 100.000 maps respectively dated 1990 and 2006 (EEA, 1990, 2006). The Land Use Map of Italy provides a fundamental documentation for diachronic land-use analysis as it is the first land-use dataset based on geo-referenced information in Italy. The harmonized land-use nomenclature used in this study is reported in Table 3S (Supplementary materials). Additional input data for model implementation are precipitation averages over 30-years time periods (1950–1970, 1980–2000 and 1990–2010). The input climate data have been derived from the meteorological network of the Regional Environmental Agency (Agenzia Regionale per l'Ambiente della Basilicata, ARPAB) with gauging stations covering homogeneously the study area. Meteorological data at the desired temporal scale were regionalized using a Spline function provided by a Geographic Information System. The 1:250.000 Soil Map of Basilicata Region (Rosa and Pesce, 2006) provided the basic information assessing soil texture. Information on soil organic matter content were derived from the Soil Profile Analytical Database of Europe (European Soil Bureau Network and the European Commission, 2004). Slope and aspect were derived from the 20 m digital terrain model provided by the Italian Ministry of the Environment (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2012). The collected spatial data were converted in raster format, harmonized and re-sampled at the resolution of 30 m for data analysis. The long-term data collected in this study are considered the most reliable and complete information set dealing with soil, climate and vegetation for Italy (Salvati et al., 2016).

3. Results and discussion

The investigated time period was partitioned in two intervals characterized by land abandonment scattered over rural areas (1960–1990) and natural expansion of vegetation resulting in a significant increase of forest land (1990–2010) concentrated in the upper left mountainous and hilly districts (Fig. 2a). Results of our model indicate a decline in soil erosion risk related to changes in the use of land between 1960 and 1990 (Fig. 2b). Forests expanded by 7.1% between 1960 and 1990 (nearly 49 km^2); agri-

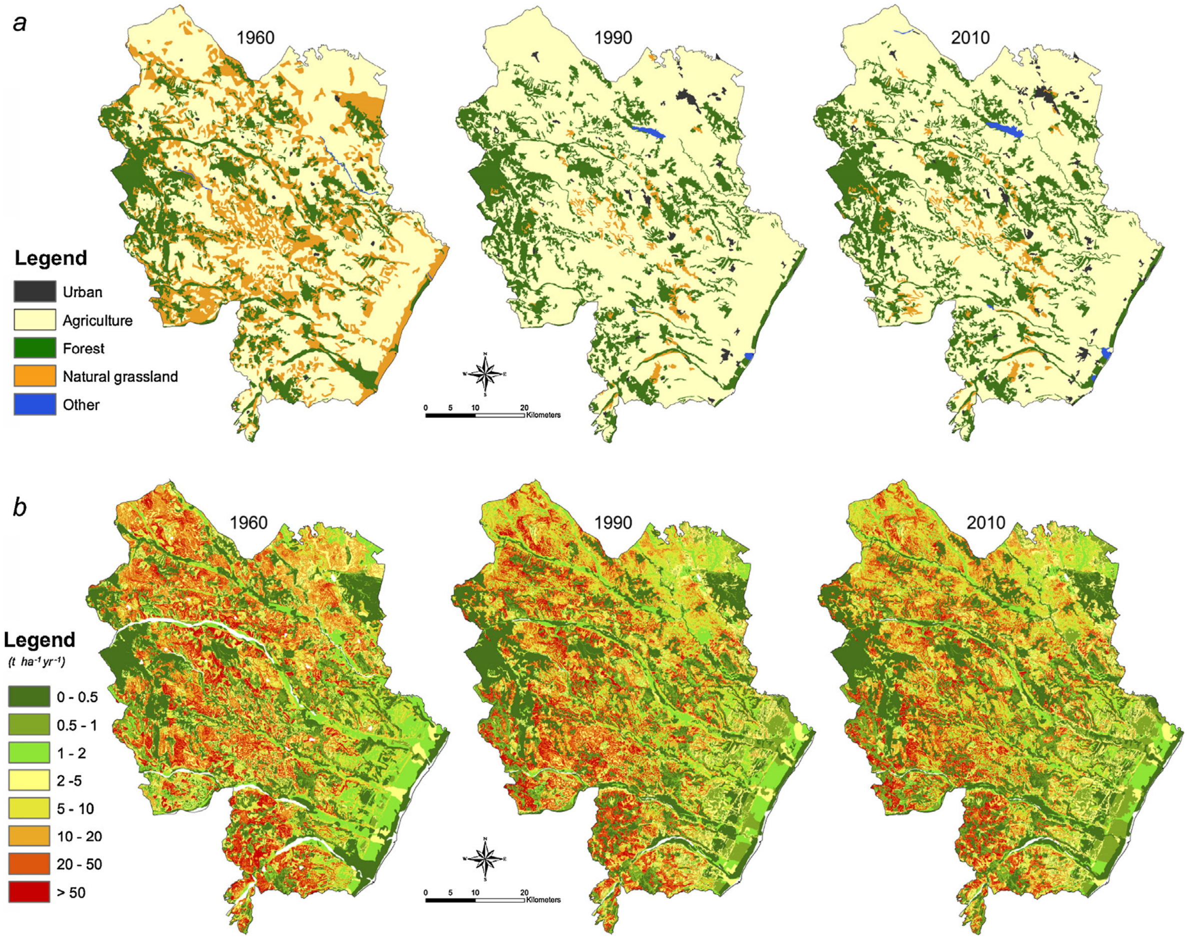

Fig. 2. Land-use maps (a) and soil erosion risk maps (b) for Matera province by year.

Table 1
Evaluation of actual erosion as function of land-use type.

Land cover (LC)	1960		1990			2010		
	Soil erosion, t ha^{-1} yr^{-1}	LC, %	Soil erosion, t ha^{-1} yr^{1}	LC, %	LC change 1960–1990, %	Soil erosion, t ha^{-1} yr^{-1}	LC, %	LC change 1990–2010, %
Forests	1.22	20.0	0.97	21.43	+ 7.15	0.96	22.52	+ 5.63
Agriculture	20.81	56.03	15.68	74.34	+32.67	14.48	71.64	−3.63
Natural grassland	2.97	23.59	1.03	2.12	−91.01	1.73	2.98	+40.68
Study area	12.61		11.86			10.58		

Table 2
Change over time in the surface area of land with tolerable erosion level (T) in the study area, Italy.

Soil loss tolerance (T) t ha^{-1} yr^{-1}	CLC Code	1960			1990			2010		
		total area	<T	> = T	total area	<T	> = T	total area	<T	> = T
		ha	%	%	ha	%	%	ha	%	%
0.5	311; 312; 313; 321; 322; 323; 324; 421	139799	47,9	52,1	74750	74,1	25,9	79754	75,6	24,4
1.0	231; 331; 333	9900	99,0	1,0	16354	65,2	34,8	17270	78,7	21,3
1.5	242; 243	–	–	–	32519	39,1	60,9	30357	41,9	58,1
2.0	241	224	73,1	26,9	26890	35,8	64,2	23430	35,4	64,6
2.5	223	23210	26,6	73,4	14671	28,0	72,0	14130	22,3	77,7
3.0	211; 212; 221; 222	168950	27,7	72,3	173563	26,3	73,7	172146	26,9	73,1
Total		342083	38,0	62,0	338747	40,8	59,2	337087	42,8	57,2

cultural area expanded by 32.6% (628 km^2) and natural grassland decreased by 91% (737 km^2) during the same time period (Table 1). The most relevant changes in the use of land occurred between 1960 and 1990 and refer to anthropogenic conversion of natural grassland to coniferous forests for soil protection reasons and to cropland stimulated by the introduction of legislative and economic incentives supporting development programs for marginal and socially-disadvantaged internal areas. These forms of landscape

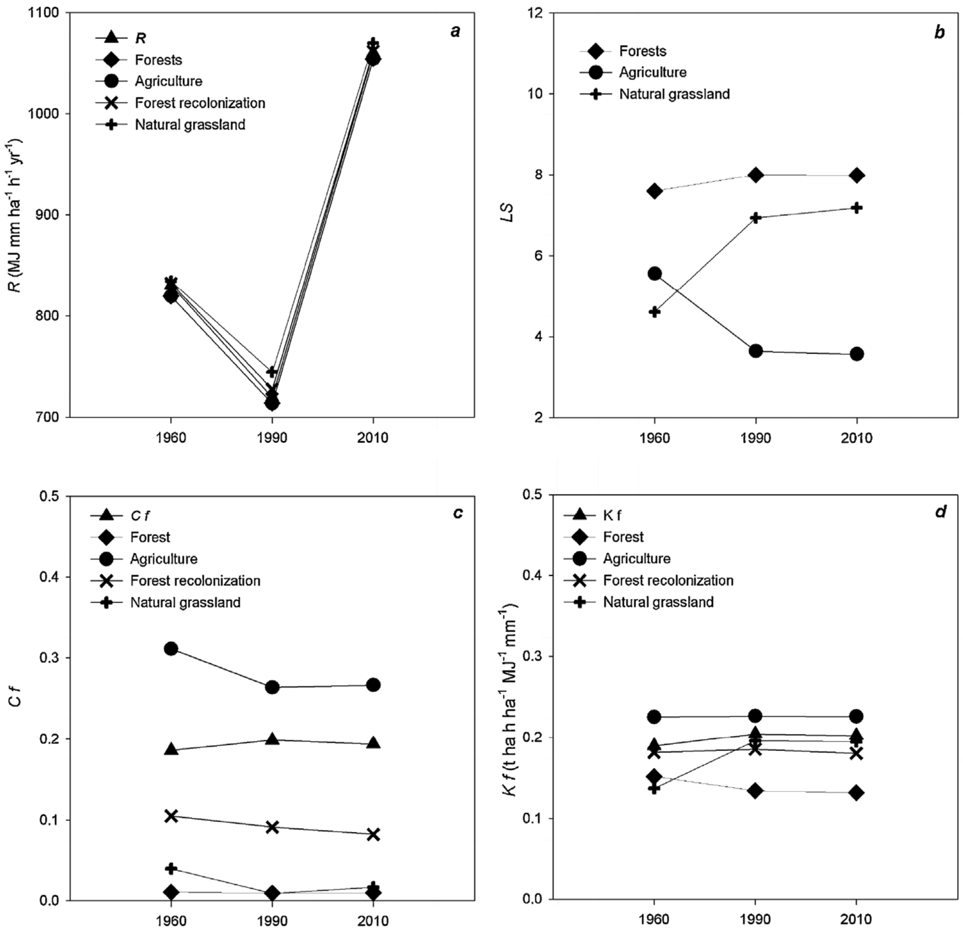

Fig. 3. Temporal patterns of USLE factors a) R, b) LS, c) C, d) K.

modification have progressively reduced since the early 1990s due to the scarce profitability of the primary sector. The consequent land abandonment indirectly stimulated the natural expansion of forests and natural grassland.

Landscape changes have contributed to reduce soil erosion risk owing to the positive effects of vegetation cover in the containment of precipitation energy, rainfall intensity and water-holding capacity. The decline in soil erosion risk was confirmed for the most recent time interval (1990–2010). Forests increased by 5.6% (nearly 37 km^2) as an indirect response to land abandonment (Mancino et al., 2014). Agricultural land decreased by 3.6%, corresponding to a loss of nearly 92.6 km^2 of productive land, and natural grassland expanded by 40.6% (nearly 29.6 km^2). The establishment of national and regional parks and protected areas in Basilicata region stimulated a generalized improvement of forest stands particularly in terms of density, age of population and biodiversity. The estimated soil erosion risk at the study site level decreased from 12.61 (t ha^{-1} year^{-1}) for 1960–11.86 (t ha^{-1} year^{-1}) for 1990 and to 10.58 (t ha^{-1} year^{-1}) for 2010. These results are consistent with evidences provided by Panagos et al. (2015a), showing an average soil loss of 8.5 t ha^{-1} yr^{-1} for Italy, with higher values for Mediterranean dryland in respect to continental areas.

The spatio-temporal variability in the parameters used for the evaluation of the USLE model was also analyzed; trends in R, LS, C and CK factors were shown in Fig. 3 and reflect a remarkable correlation between soil erosion risk and land-use changes. In accordance with the results proposed by Panagos et al. (2015a), the main parameters contributing to soil erosion risk are the slope length factor (LS) and the land Cover management factor (C). Rainfall erosivity shows a continuous increase over the study period (Fig. 3a), confirming that the decrease in soil erosion risk is the result of land-use changes, reflected in the decline of the C factor. The LS factor showed a significant reduction between 1960 and 1990 for agricultural land-use classes. The increase of the LS factor for natural grassland (Fig. 3b) between 1960 and 1990 reflects the expansion of cropland over lower slopes. However, the increase of the LS factor for natural grassland did not affect soil erosion at the spatial level of study area due to the restricted surface of grassland.

The simplified parameterization of the R factor based on the average annual rainfall may underestimate the erosivity factor due to heavy rains. However, the outcome of our model (946.3) is consistent with the R factor estimated by Panagos et al. (2015b) for Europe based on rainfall erosivity (967.2). The main difference between the two approaches refers to the use of a different R factor range, possibly representing a more accurate spatial variability of R factor. The slight increase of the C factor for forests (Fig. 3c) results from the expansion of schlerophyllous vegetation, mainly due to expansion of natural vegetation following land abandonment, and to human-driven degradation of broad-leaved forests progressively transformed into schlerophyllous vegetation and shrubland. Changes in the CK factor (soil erodibility factor K combined with the Crusting Index CI) were also related to land-use changes (Fig. 3d). The CK factor increased for natural grassland as a result of the expansion of intensive agriculture into areas with high soil quality. As a consequence, the relict soils covered by natural grasslands displayed structurally low levels of soil organic matter. By removing the CI, the largest modifications in the K factor were observed for natural grassland and cropland; forests and areas with forest recolonization showed only moderate differences in the K factor by removing the corresponding CI value.

The lowest level of soil erosion was observed in areas with the highest level of forest cover. Based on the soil loss tolerance (T), a reduction of the surface area characterized by T values over tolerable levels for the different land-use classes was observed over the study period (62% in 1960: 2122 km^2, 59.2% in 1990: 2006 km^2 and 57.2% in 2010: 1928 km^2). The largest decline was observed in areas with forests and natural grassland (0.5 t ha^{-1} yr^{-1} T threshold), confirming the key role of these classes in the containment of soil erosion risk. For areas characterized by T values from 1 to 2, the results show an increase of the areas with T over the limits, mainly between 1960 and 1990. However the moderate extent of these areas, covering nearly 100 km^2, did not affect the soil loss tolerance at the level of study area.

4. Conclusions

This study proposes a modified USLE model to incorporate the impact of long-term landscape dynamics on soil erosion. The spatio-temporal analysis of the main parameters contributing to model's performance indicates the key role of Slope Length factor (LS) and the Cover management factor (C), in full accordance with the evidence provided by Panagos et al. (2015a). Our results pointed out the key role of vegetation cover – particularly forests – in the mitigation of soil erosion risk. Forests revealed especially important in the conservation of marginal rural land characterized by steep slopes and fragmented land cover (Bajocco et al., 2012; Salvati et al., 2013b). The proposed methodological approach and the simplified model's specification for selected USLE parameters, contribute to increase model flexibility in presence of high spatial resolution datasets (Panagos et al., 2015a). Finally, the present study confirms the USLE model adaptability to spatial information with different quality and resolution.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2016.07.040.

References

APAT, 2004. Elementi di progettazione della Rete Nazionale di monitoraggio del suolo ai fini ambientali (Versione aggiornata sulla base delle indicazioni contenute nella stategia tematica del suolo dell'Unione Europea). All. 4 a cura di Bazzoffi, P., Giandon, P., Francaviglia, R., Benedetti, A., Trinchera, A., CTN_TES – TES-T-MAN-03-02.

Adediji, A., Tukur, A.M., Adepoju, K.A., 2010. Assessment of revised universal soil loss equation (RUSLE) in katsina area, katsina state of Nigeria using remote sensing (RS) and geographic information system (GIS). Iran. J. Energy Environ. 1 (3), 255–264.

Bajocco, S., De Angelis, A., Perini, L., Ferrara, A., Salvati, L., 2012. The impact of land use/land cover changes on land degradation dynamics: a mediterranean case study. Environ. Manage. 49 (5), 980–989.

Borrelli, P., Panagos, P., Märker, M., Modugno, S., Schütte, B., 2016. Assessment of the impacts of clear-cutting on soil loss by water erosion in Italian forests: first comprehensive monitoring and modelling approach. Catena, http://dx.doi.org/10.1016/j.catena.2016.02.017.

CNR & Directorate General of Cadastre (1956–1960) Land use map of Italy in scale 1:200.000. Italian Touring Club, Milano.

Caraveli, H., 2000. A comparative analysis on extensification and intensification in Mediterranean agriculture: dilemmas for LFAs policy. J. Rural Stud. 16, 231–242.

Conacher, A.J., Sala, M., 1998. Land Degradation in Mediterranean Environments of the World. Wiley, Chichester.

Cook, D.J., Dickinson, W.T., Rudra, R.P., 1985. G.A.M.E.S.: Guelph Model for Evaluating the Effects of Agricultural Management Techniques on Erosion and Sedimentation – User's Manual. School of Engineering, University of Guelph.

de Vente, J., Poesen, J., Bazzoffi, P., Van Rompaey, A., Verstraeten, G., 2006. Predicting catchment sediment yield in Mediterranean environments: the importance of sediment sources and connectivity in Italian drainage basins. Earth Surf. Process. Landf. 31, 1017–1034.

Dissmeyer, G.E., Foster, G.R., 1980. A Guide for Predicting Sheet and Rill Erosion on Forest Land. Technical Publication SA-TP-11. USDA Forest Service and Private Forestry-Southeastern Area.

EEA, Corine Land Cover, 1990. (CLC1990). Seamless Vector Database Published: 2004. European Environment Agency.

EEA, Corine Land Cover 2006. (CLC2006) Seamless Vector Database Published: 2010. European Environment Agency.

European Soil Bureau Network and the European Commission, 2004. European Soil Database version 2.0. March 2004. EUR 19945 EN. Available from http://eusoils.jrc.ec.europa.eu/ESDB_Archive/ESDBv2/index.htm.

Ferrara, A., Salvati, L., Sabbi, A., Colantoni, A., 2014. Soil resources, land cover changes and rural areas: towards a spatial mismatch? Sci. Total Environ. 478, 116–122.

García-Ruiz, J.M., Nadal-Romero, E., Lana-Renault, N., Beguería, S., 2013. Erosion in Mediterranean landscapes: changes and future challenges. Geomorphology 198, 20–36.

Grimm, M., Jones, R., Montanarella, L., 2002. Soil Erosion Risk in Europe. European Commission, Institute for Environment and Sustainability, European Soil Bureau.

Grimm, M., Jones, R.J.A., Rusco, E., Montanarella L., 2003. Soil Erosion Risk in Italy: a revised USLE approach. European Soil Bureau Research Report No.11, EUR 20677 EN, (2002), 28pp. Office for Official Publications of the European Communities, Luxembourg.

Kinell, P.I.A., 2007. Runoff dependent erosivity and slope length factors suitable for modelling annual erosion using the Universal Soil Loss Equation. Hydrol. Process. 21, 2681–2689.

Kosmas, C., Gerontidis St Marathianou, M., 2000. The effect of land use change on soils and vegetation over various lithological formations on Lesvos (Greece). Catena 40, 51–68.

Kosmas, C., Danalatos, N.G., Cammeraat, L.H., Chabart, M., Diamantopoulos, J., Farand, R.L., Gutierrez, L., Jacob, A., Marques, H., Martinez Fernandez, J., 1997. The effect of land use on runoff and soil erosion rates under Mediterranean conditions. Catena 29, 45–59.

Koulouri, M., Giourga, C., 2007. Land abandonment and slope gradient as key factors of soil erosion in Mediterranean terraced lands. Catena 69 (3), 274–281.

Lee, G.S., Lee, K.H., 2006. Scaling effect for estimating soil loss in the RUSLE model using remotely sensed geospatial data in Korea. Hydrol. Earth Syst. Sci. 3, 135–157.

Liu, B.Y., Nearing, M.A., Shi, P.J., Jia, Z.W., 2000. Slope length effects on soil loss for steep slopes. Soil Sci. Soc. Am. J. 64 (5), 1759–1763.

MacDonald, D., Crabtree, J.R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Gibon, A., 2000. Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. J. Environ. Manage. 59 (1), 47–69.

Mancino, G., Nolè, A., Ripullone, F., Ferrara, A., 2014. Landsat TM imagery and NDVI differencing to detect vegetation change: assessing natural forest expansion in Basilicata, southern Italy. iForest 7, 75–84.

McCormack, D.E., Young, K.K., Kimberlin, L.W., 1982. Current criteria for determining soil loss tolerance. Determinants of Soil Loss Tolerance, 95. American Society Agronomy, pp. 111.

Ministero dell'Ambiente e della Tutela del Territorio e del Mare – Geoportale nazionale, 2012. Modello digitale del terreno (DTM), 20, metri. http://www.pcn.minambiente.it/GN/.

Mitasova, H., 1996. GIS Tools for Erosion/Deposition Modelling and Multidimensional Visualization. Part III: Process Based Erosion Simulation. Geographic Modelling and Systems Laboratory, University of Illinois.

Montanarella, L., 2007. Climate and land degradation. In: Sivakumar, M.V.K., N'diangui, N. (Eds.), Trends in Land Degradation in Europe. Springer, Berlin, pp. 83–104.

Morgan, R.P.C., 2005. Soil Erosion and Conservation. Blackwell, London.

Nasiri, M., 2013. GIS modelling for locating the risk zone of soil erosion in a deciduous forest. J. For. Sci. 59 (2), 87–91.

Nolè, A., Law, B.E., Magnani, F., Matteucci, G., Ferrara, A., Ripullone, F., Borghetti, M., 2009. Application of the 3-PGS model to assess carbon accumulation in forest ecosystems at a regional level. Can. J. For. Res. 39 (9), 1647–1661.

Nunes, A.N., Coelho, C.O.A., Almeida, A.C., Figueiredo, A., 2010. Soil erosion and hydrological response to land abandonment in a central Inland area of Portugal. Land Degrad. Dev. 21 (3), 260–273.

Nunes, A.N., Almeida, A.C., Coelho, C.O.A., 2011. Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. Appl. Geogr. 31 (2), 687–699.

OECD, 2001. Environmental indicators for agriculture. Methods and results, vol. 3. In: OECD (ed), Agriculture and food. ISBN 92-4-18614-X, p. 409.

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., Alewell, C., 2014. Soil erodibility in Europe: a high-resolution dataset based on LUCAS. Sci. Total Environ. 479–480, 189–200.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C., 2015a. The new assessment of soil loss by water erosion in Europe. Environ. Sci. Policy 54, 438–447.

Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., et al., 2015b. Rainfall erosivity in europe. Sci. Total Environ. 511, 801–814.

Panagos, P., Borrelli, P., Meusburger, C., Alewell, C., Lugato, E., Montanarella, L., 2015c. Estimating the soil erosion cover-management factor at European scale. Land Use Policy 48C, 38–50.

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E.H., Poesen, J., Alewell, C., 2015d. Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European Scale. Environ. Sci. Policy 51, 23–34.

Panagos, P., Borrelli, P., Meusburger, K., 2015e. A new European slope length and steepness factor (LS-Factor) for modeling soil erosion by water. Geosciences 5, 117–126.

Quinton, J.N., Govers, G., Van Oost, K., Bardgett, R.D., 2010. The impact of agricultural soil erosion on biogeochemical cycling. Nat. Geosci. 3 (5), 311–314.

Razafindrabe, B.H., He, B., Inoue, S., Ezaki, T., Shaw, R., 2010. The role of forest stand density in controlling soil erosion: implications to sediment-related disasters in Japan. Environ. Monit. Assess. 160 (1-4), 337–354.

Renard, K.G., Foster, G.R., Weesies, G.A., Porter, J.P., 1991. RUSLE: revised universal soil loss equation. J. Soil Water Conserv. 46 (1), 30–33.

Renard, K.G., Foster, G.R., Weesies, G.A., 1997. Predicting Soil Erosion by Water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agricultural Handbook No 703:404.

Rosa R., Pesce F., 2006. Carta dei suoli della Basilicata, Regione Basilicata, Potenza.

Salvati, L., Ferrara, A., 2014. Do land cover changes shape sensitivity to forest fires in peri-urban areas? Urban For. Urban Green. 13 (3), 571–575.

Salvati, L., De Angelis, A., Bajocco, S., Ferrara, A., Barone, P.M., 2013a. Desertification risk, long-term land-use changes and environmental resilience: a case study in basilicata, Italy. Scott. Geogr. J. 129 (2), 85–99.

Salvati, L., De Zuliani, E., Sateriano, A., Zitti, M., Mancino, G., Ferrara, A., 2013b. An expert system to evaluate environmental sensitivity: a local-scale approach to land degradation. Appl. Ecol. Environ. Res. 11 (4), 611–627.

Salvati, L., Zitti, M., Perini, L., 2016. Fifty years on: long-term patterns of land sensitivity to desertification in Italy. Land Degrad. Dev. 27 (2), 97–107.

SOER, 2010. The European environment – state and outlook 2010. Publications Office of the European Union, European Environment Agency.

Soil Survey Division Staff, 1993. Soil Survey Manual. United States Department of Agriculture, Handbook n (18. Washington Stone RP, Hilborn D (2000) Fact sheet, Universal Soil Loss Equation. Ministry of Agriculture, Food and Rural Affairs, Ontario.

Stone, R.P., Hilborn, D., 2000. Universal Soil Loss Equation (USLE) EPA Region 10 with the technical assistance of Science Applications.

Stumpf, F., Auerswald, K., 2006. HochaufgeÏoste Erosionsprognosekarten von Bayern. Tech. rept. Technische Universitat Munchen, Munchen.

Šúri, M., Cebecauer, T., Hofierka, J., Fulajtár, E., 2002. Soil erosion assessment of Slovakia at a regional scale using GIS. Ekoloógia 21 (4), 404–422.

Van Vliet, L.J.P., Wall, G.J., Dickinson, W.T., 1976. Effects of agricultural land use on potential sheet erosion losses in Southern Ontario. Can. J. Soil Sci. 56, 443–451.

Van der Knijff, J.M., Jones, R.J.A., Montanarella, L., 1999. Soil Erosion Risk Assessment in Italy. European Soil Bureau, EUR 19044 EN.

Van der Knijff, J.M., Jones, R.J.A., Montanarella, L., 2000. Soil Erosion Risk Assessment in Europe. Office for Official Publications of the European Communities, Luxembourg, EUR 19044 EN.

Verheijen, F.G.A., Jones, R.J.A., Rickson, R.J., Smith, C.J., 2009. Tolerable versus actual soil erosion rates in Europe. Earth Sci. Rev. 94, 23–38.

Wall, G.J., Coote, D.R., Pringle, E.A., Shelton, I.J., 2002. RUSLEFAC — Revised Universal Soil Loss Equation for Application in Canada: A Handbook for Estimating Soil Loss from Water Erosion in Canada. Research Branch, Agriculture and Agri-Food Canada. Ottawa.C ontribution No. AAFC/AAC2244E.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses –a guide for conservation planning. Agriculture Handbook, 537. U.S. Department of Agriculture.

Zachar, D., 1982. Soil Erosion. Elsevier, Bratislava.

Zhou, Z.P., Shangguan, D.L., Zhao, 2006. Modeling vegetation coverage and soil erosion in the Loess Plateau area of China. Ecol. Modell. 198 (1-2), 263–268.