Soil Erosion Risk in Italy: a revised USLE approach

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EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Institute for Environment and Sustainability

2003

EUR 20677 EN

This document may be cited as follows:

Mirco Grimm, Robert J.A. Jones, Ezio Rusco and Luca Montanarella (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.

COVER PICTURE

BADLANDS OF VAL CAMONICA, LOMBARDIA

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Mirco Grimm, Robert J A Jones

Ezio Rusco and Luca Montanarella

European Soil Bureau,
Institute for Environment & Sustainability
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EUR 20677 EN

Printed in Italy

SUMMARY

In 1999, the well-known Universal Soil Loss Equation (USLE) was used by the European Soil Bureau to produce a map of the soil erosion risk assessment in Italy. This report describes the refinement of the methodology used to produce this map firstly by improving the way the influence of rainfall is calculated (R–factor) and secondly by introducing susceptibility of the soil to surface crusting to create a better erodibility factor (K–factor). For recalculating the R-factor, a new data set of rainfall totals from 366 meteorological stations, spread throughout Italy, has been used. The new K-factor was calculated by incorporating a recent modelling approach developed by INRA, Orleans, to estimate the influence of surface soil crusting. Susceptibility to surface crusting was determined by applying a series of pedo-transfer rules to the European Soil Database at 1:1,000,000 scale. The resulting soil crusting index gives a clear indication of the likelihood of a surface crust forming.

The main outcome is that estimated annual soil losses in hilly and the mountainous area (e.g. Alps and Apennines) are larger using the modified R- and K- factors than in the previous analysis. However, there is still much scope for improving assessments of soil erosion risk in Italy by applying the USLE-model and other models in combination with data sets. For example, the calculation of the R-factor could be further improved by accessing long-term rainfall totals. The K-factor could be improved with more accurate information on soil texture and organic matter. More accurate L- and S-factors (Slope length and Slope angle) could be calculated using a finer scale DEM, e.g at 50m x 50m. However, the results from this work probably represent the best assessments of erosion risk in Italy that can be obtained using currently available spatial data.

TABLE OF CONTENTS

1 INTRODUCTION **1**

2 UNIVERSAL SOIL LOSS EQUATION – USLE **2**

2.1 R-factor **2**

2.2 K-factor **3**

3 MODIFICATION OF THE EROSIVITY – R-FACTOR **6**

4 MODIFICATION OF ERODIBILITY INCORPORATING CRUSTING INDEX **13**

5 REVISED ESTIMATES OF SOIL LOSS **19**

6 REFERENCES **23**

TABLE OF FIGURES

1	Meteorological stations of MARS (1989 – 1998)	3
2	Soil Erodibility Factor (K-Factor) – (After Van der Knijff et al.,1999)	4
3	Annual erosion risk in Italy (After Van der Knijff et al.,1999, 2002)	5
4	Meteorological stations (1931 – 1960)	6
5	Variation of R^2 between average monthly rainfall and altitude, latitude and average yearly rainfall throughout the year	7
6	Average annual rainfall (mm) in Italy, derived from 366 meteorological stations, for the period 1931 – 1960	8
7	Monthly rainfall (mm) January to April	9
8	Monthly rainfall (mm) May to August	10
9	Monthly rainfall (mm) September to December	11
10	Chaining of data from the SGDBE (After Le Bissonnais, 1998)	13
11	Soil loss and surface crusting after a heavy rain storm in North Italy (Varese, Lombardia, Italy), April 2002	14
12	Crusting factor	16
13	Crusting K-factor	17
14	Seasonal erosion risk in Italy	19
15	Annual erosion risk in Italy	20
16	Differences between USLE and R- and K- modified USLE	21
17	Potential annual erosion risk in Italy	22

1 Introduction

In 1999, a project was initiated in Italy to assess erosion risk at national level. The aim was to create a map that could be used for identifying the regions that are most prone to erosion. There are several models available for assessing erosion risk but a primary consideration was the need to provide quantitative estimates of sediment loss. For this reason, the well-known Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) was used to elaborate a map of the soil erosion risk assessment in Italy (Van der Knijff *et al,* 1999, 2002). The USLE model is suitable only for estimating rill and inter-rill erosion caused by water. It integrates a number of factors that can be determined from available data. One of the factors is the rain and runoff-factor (R-factor), also called the soil erosivity factor. This factor determines the erosive effect of precipitation on soil loss. Another factor is the erodibility or K-factor. This determines the influence of soil properties on soil loss during rainfall events.

The overall aim of this work was to refine the map of soil erosion risk assessment in Italy, produced by Van der Knijff *et al.* (1999, 2002). Incorporating the influence of rainfall on soil loss is one component of this improvement. Another is the refinement of the susceptibility of the soil to surface crusting and using a new soil data set for Italy to produce a better erodibility factor.

For recalculating the R-factor a new data set of rainfall totals from 366 meteorological stations spread throughout Italy has been used. As a first step the spatial distribution of the monthly rainfall was determined using a regression equation incorporating altitude, latitude and average annual rainfall. From the monthly rainfall a new monthly R-factor was derived to assess a new soil erosion risk for Italy.

A new K-factor has been calculated by applying a recent modelling approach that has been adopted by INRA (Institut National de Recherche Agronomique), Orleans, to estimate soil erosion risk in France and in Europe (Le Bissonnais and Daroussin, Pers Comm.2001). In this model, the influence of surface soil crusting is taken into account in addition to texture. Susceptibility to surface crusting was determined by applying a series of pedo-transfer rules to the European Soil Database at 1:1,000,000 scale. The resulting soil crusting index (CI) gives a clear indication of the likelihood of a surface crust forming. The harder the surface crust the more difficult it is for water to infiltrate into the soil thereby exacerbating surface runoff and increasing erosion of the soil particles. The other USLE factors – slope (S, L) and crop cover (C), calculated by Van der Knijff *et al.* (1999, 2002), have not been changed.

2 Universal Soil Loss Equation – USLE

The USLE is based on the following factors that are used to compute the mean annual soil loss:

$$A = R \cdot K \cdot L \cdot S \cdot C \qquad (1.1)$$

Where:

A = Mean annual soil loss

R = Rainfall erosivity factor

K = Soil erodibility factor

L = Slope length factor

S = Slope factor

C = Cover management factor

This report focuses on the changes made for refining the R-factor and the K-factor. The following sections give a short overview of the original elaboration of these two factors. A more detailed description of the procedures and the data that were used to estimate the R, the K and other factors, and the discussion on implementing the USLE can be found in Van der Knijff *et al.* (1999, 2002).

2.1 R-factor

In the original project (Van der Knijff *et al.* 1999, 2002), the R-factor was determined by applying a regression analyses on the data from 47 meteorological stations stored in the meteorological database of MARS (Monitoring Agriculture with Remote Sensing) (Figure 1). This database contains meteorological data for the period 01.01.1989 to 31.12.1998. The locations of the 47 meteorological stations are shown in Figure 1 in relation to altitude. Van der Knijff *et al.* (1999) plotted annual rainfall figures against station altitude, longitude, latitude, and distance to coast, which revealed a clear relationship between rainfall and latitude for Italy.

Van der Knijff *et al.* (1999) then calculated the annual R-factor from the equation:

$$R = a \cdot P_j \qquad (1.2)$$

Where:

P_j : Annual rainfall (mm)

a : Van der Knijff *et al.* (1999) used a value of 1.3

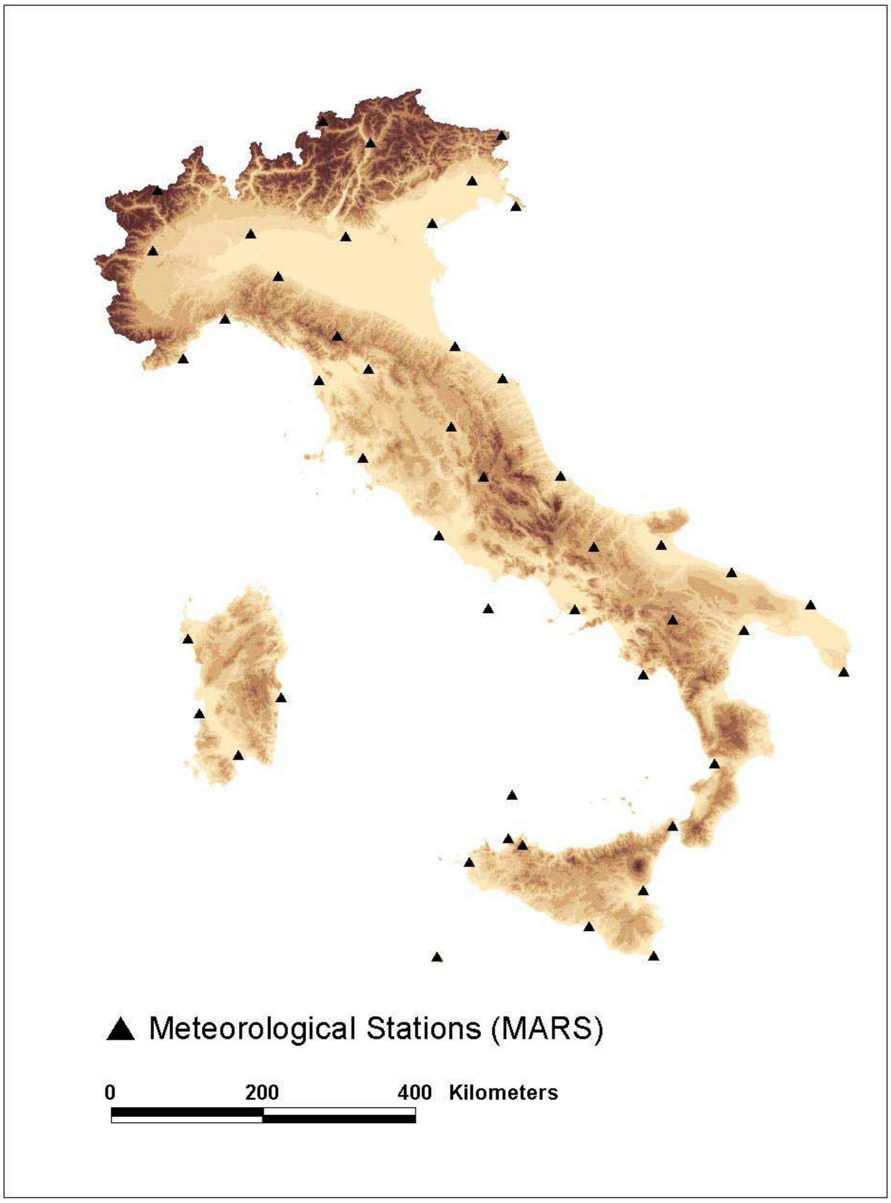

Figure 1: Meteorological stations of MARS (1989 – 1998)

2.2 K-factor

The K-factor in the original study (Van der Knijff *et al.*, 1999, 2002) was determined by applying pedo-transfer rules to the European Soil Database at 1:1,000,000 scale. For every 'soil typological unit' (STU), a K-factor was assigned on the basis of the dominant surface textural class, this assignment being modified in a few cases according to parent material. Table 1 shows the representative texture parameters for each texture class and the resulting K-factors.

***Table 1: Representative parameters for each texture class** (van der Knijff et al. 1999)*

TEXT	Dominant surface textural class in STU.	Clay%	Silt %	Sand%	K
0	No information	-	-	-	
9	No texture (histosols, ...)	-	-	-	
1	Coarse (clay < 18 % and sand > 65 %)	9	8	83	0.0115
2	Medium (18% < clay < 35% and sand > 15%, or clay < 18% and 15% < sand < 65%)	27	15	58	0.0311
3	Medium fine (clay < 35 % and sand < 15 %)	18	74	8	0.0438
4	Fine (35 % < clay < 60 %)	48	48	4	0.0339
5	Very fine (clay > 60 %)	80	20	0	0.0170

The relative erodibility of the soils in Italy, as estimation from the K-factor calculated by Van der Knijff *et al.* (1999, 2002), is shown in Figure 2.

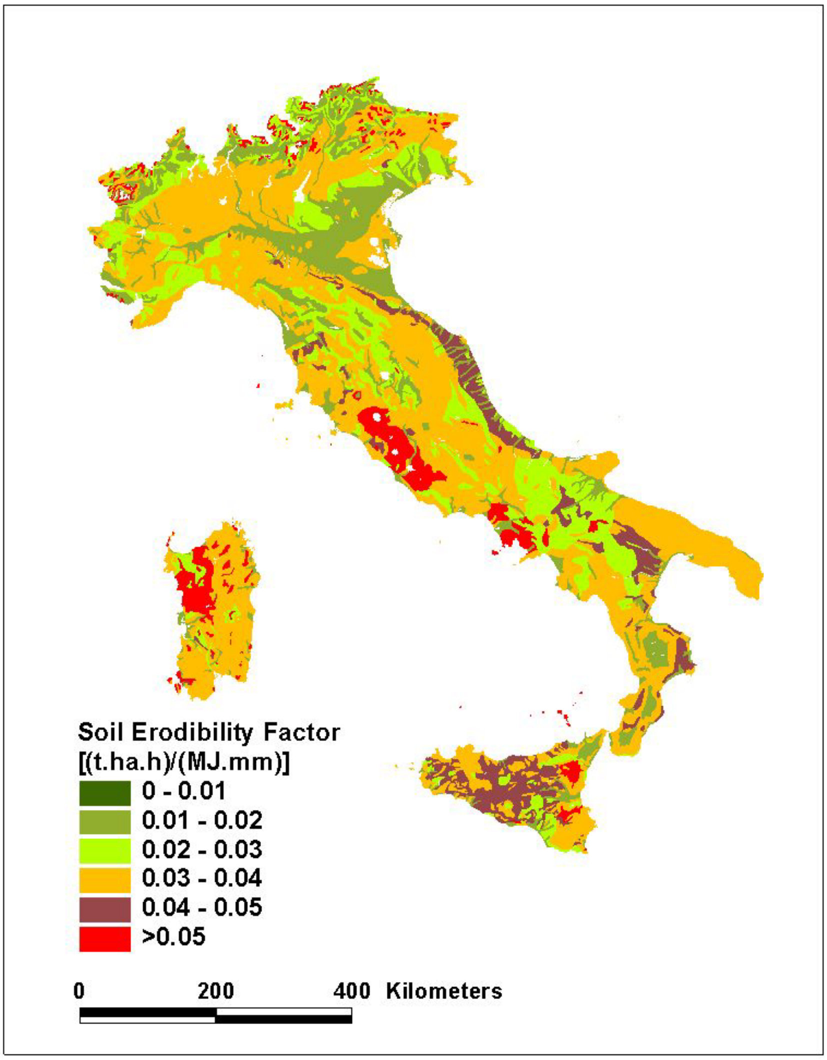

Figure 2: Soil Erodibility Factor (K-Factor)
(After Van der Knijff et al.,1999)

The approximate annual soil loss using the R and K as calculated above, on a 250m x 250m grid, is shown in Figure 3.

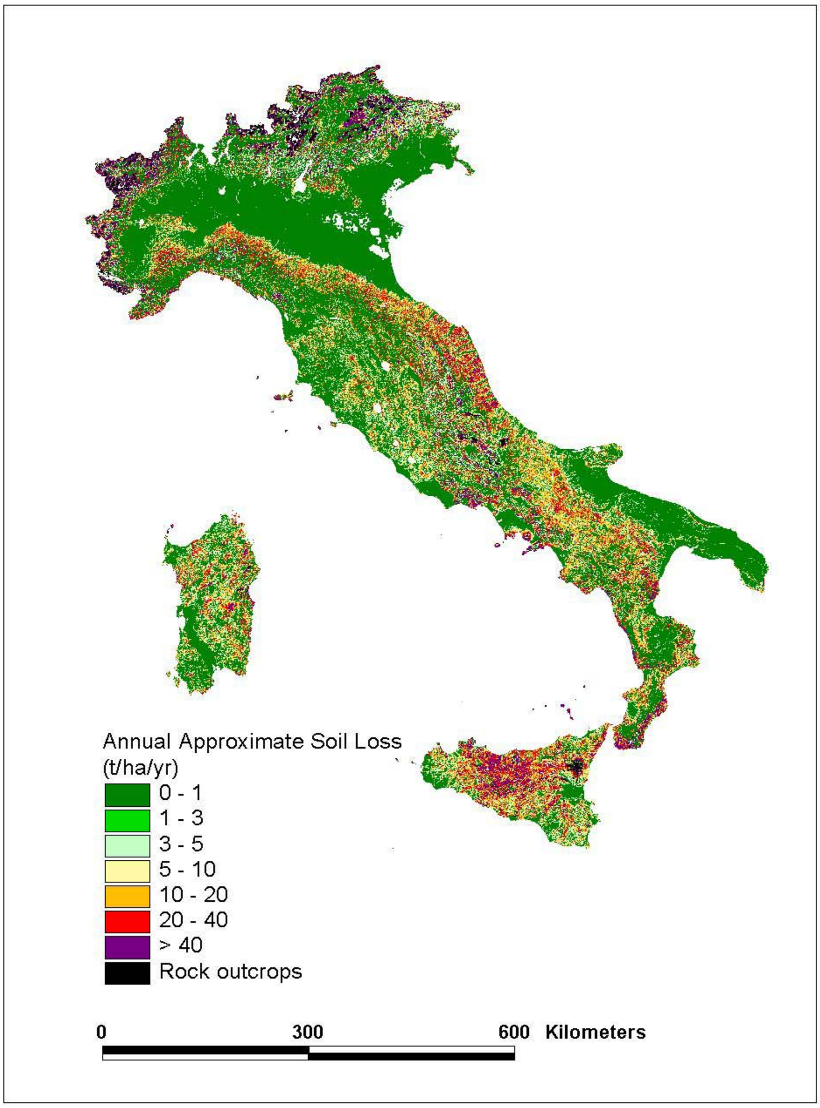

Figure 3: Annual erosion risk in Italy (After Van der Knijff et al.,1999, 2002)

3 Modification of the Erosivity – R-factor

A national data set of 366 meteorological stations provided the monthly rainfall totals for the period 1931 to 1960. Where the measuring stations are in close proximity, the data have been compared with those from the 47 MARS meteorological stations. Despite the measurement periods being different for these two data sets, the real advantage is spatial, the number of meteorological stations in the national data set distributed all over Italy being much larger than for MARS. This is essential for improving the spatial distribution of monthly rainfall in Italy and therewith the R-factor.

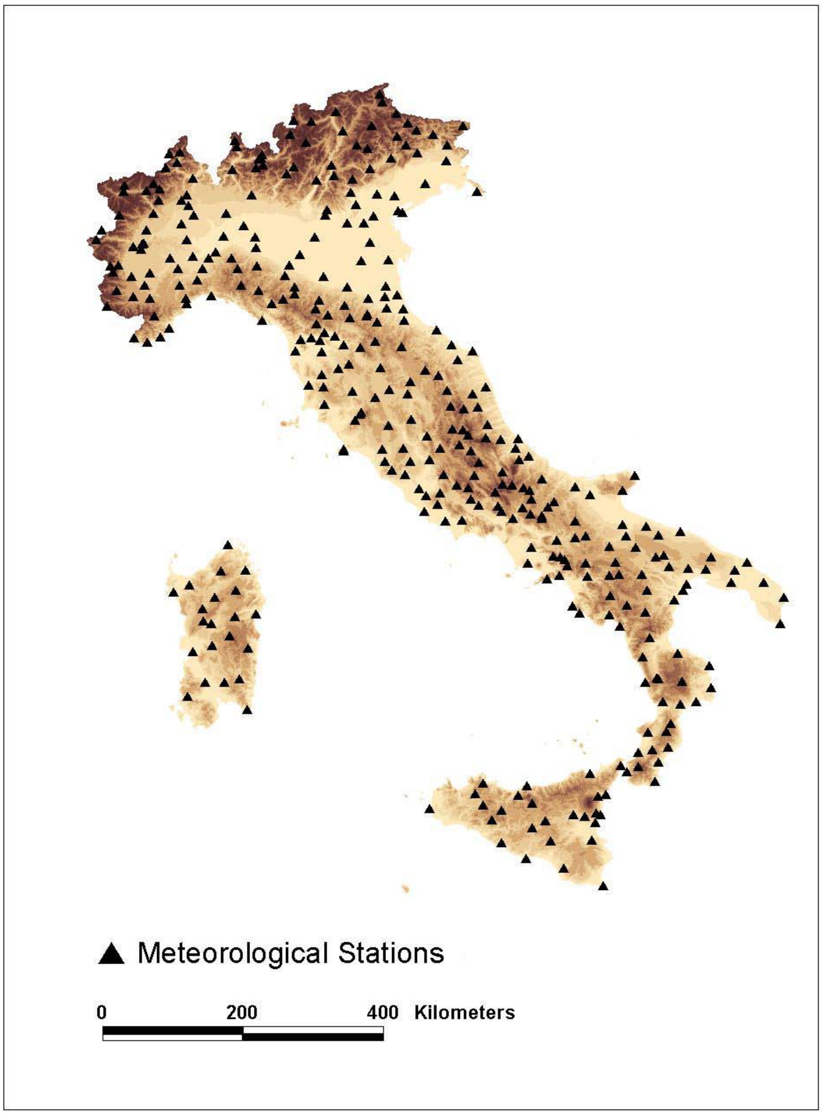

Figure 4: Meteorological stations (1931 – 1960)

The locations of the national meteorological stations (all of them below 2000 m asl) are shown in Figure 4 with an altitude background. Stations above 2000 m asl were excluded because much the winter precipitation over 2000m falls as snow. For every meteorological station, information about longitude, latitude and altitude are given.

The distance to coast of each station was likewise calculated. The rainfall data from these meteorological stations were analysed then to obtain a spatial distribution of average monthly rainfall over the whole of Italy (dependent variable). Multiple regression analyses were used to determine the influence of the different parameters such as the station altitude, longitude, latitude, distance-to-coast and annual rainfall (independent variables). The effects of longitude and distance to coast on monthly rainfall, for the Italian conditions, were found to be very small, whereas there was a strong relationship between monthly rainfall and altitude, latitude and annual rainfall[1].

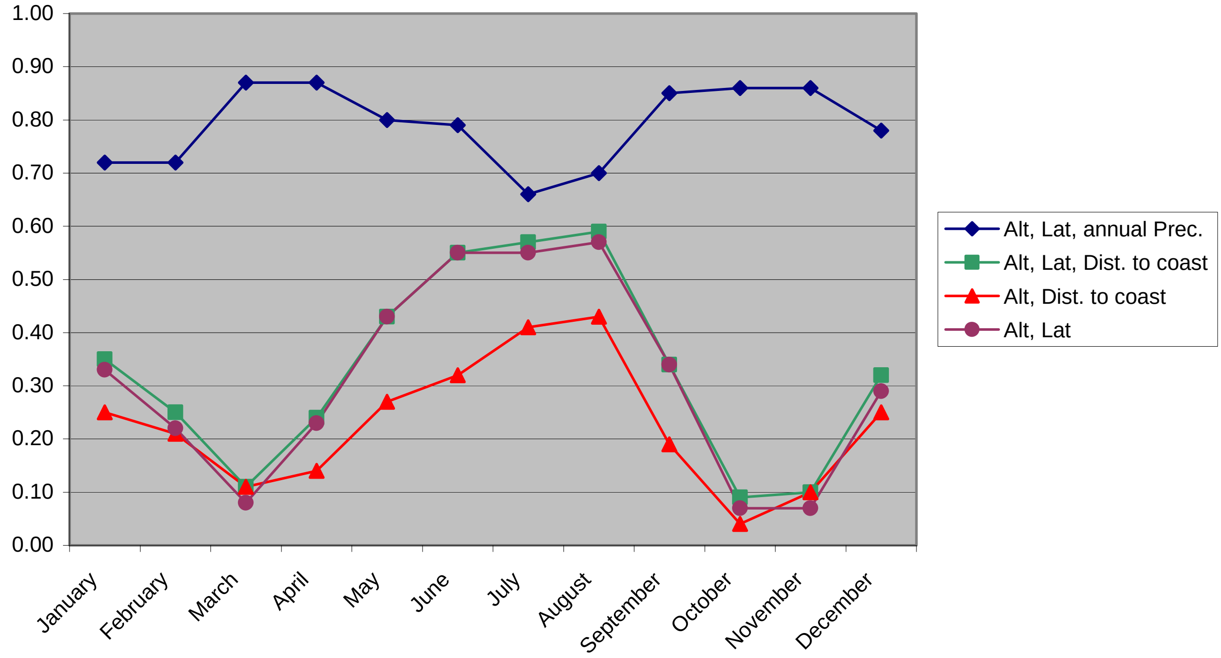

Figure 5: Variation of R^2 between average monthly rainfall and altitude, latitude and average yearly rainfall throughout the year

Figure 5 shows the monthly variation of R^2 using different combinations of parameters in the regression analyses. For the combination latitude, altitude and annual rainfall, the R^2 values (blue spots) were greater than 0,6 in all twelve months, and greater than 0.8 for five months. Thus the equation that is assumed to best predict the average monthly rainfall is as follows:

$$P_m(x) = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 \qquad (1.3)$$

Where:

$P_m(x)$	: Monthly rainfall (mm)
a_0 - a_3	: regression constant
x_1	: latitude
x_2	: altitude
x_3	: average annual rainfall

[1] It is possible that in other regions or countries (e.g. Germany or Poland) monthly rainfall is more strongly related to longitude and distance to coast.

A 1km x 1km grid was generated and equation 1.2 applied using the latitude from the grid. For altitude, the 250m x 250m grid DTM of Italy was used. The average annual rainfall (AAR) was then derived from the 366 meteorological stations. The AAR data were interpolated at a resolution of 5km x 5km using nearest neighbour analysis (Figure 6). A correction for altitude, latitude or distance from the sea was not included. In future, a digital average annual rainfall map for Italy could provide an alternative source for AAR.

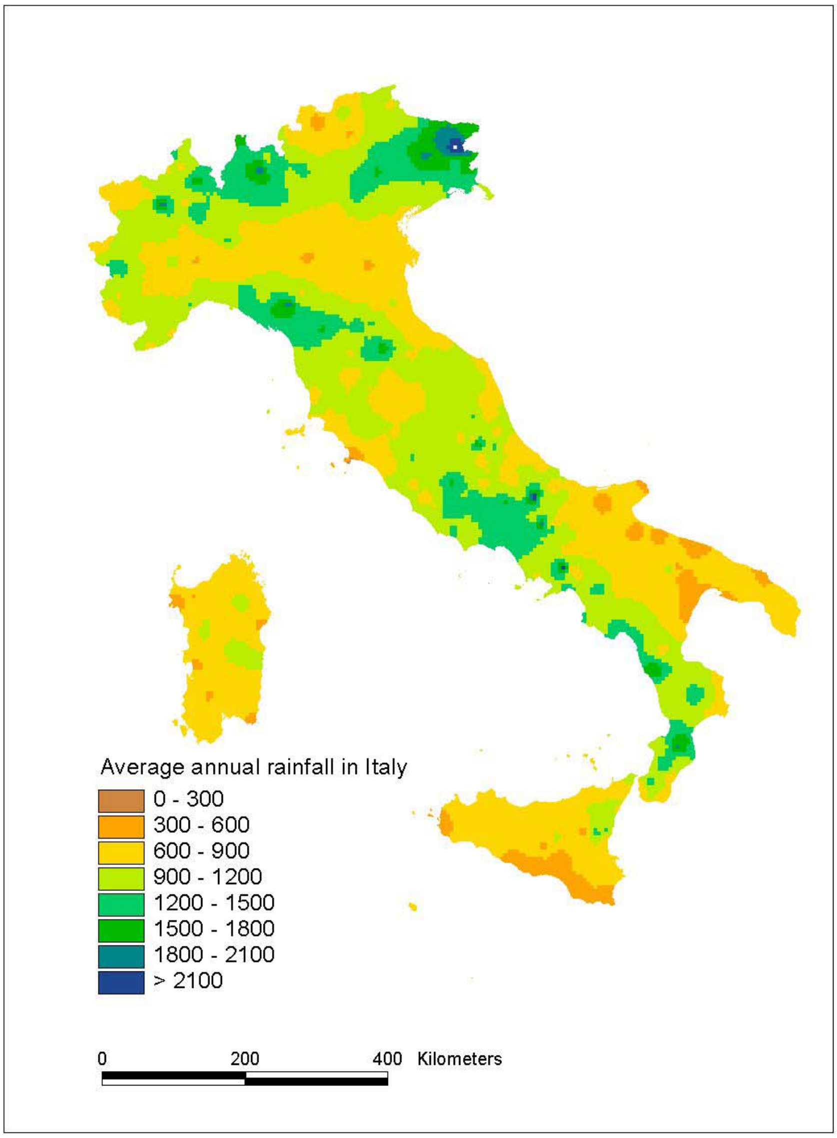

Figure 6: Average annual rainfall (mm) in Italy, derived from 366 meteorological stations, for the period 1931 – 1960

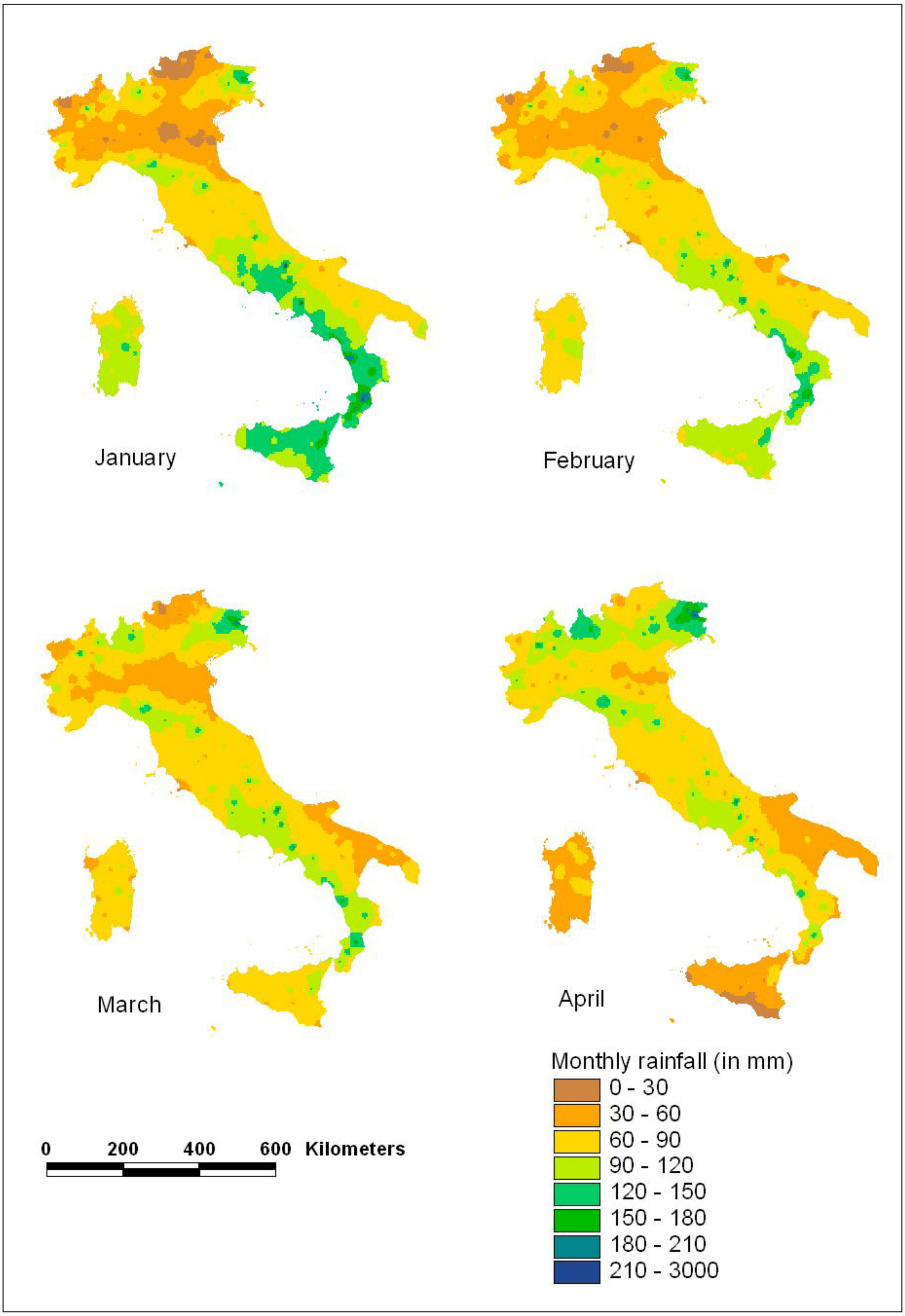

Figure 7: Monthly rainfall (mm) January to April

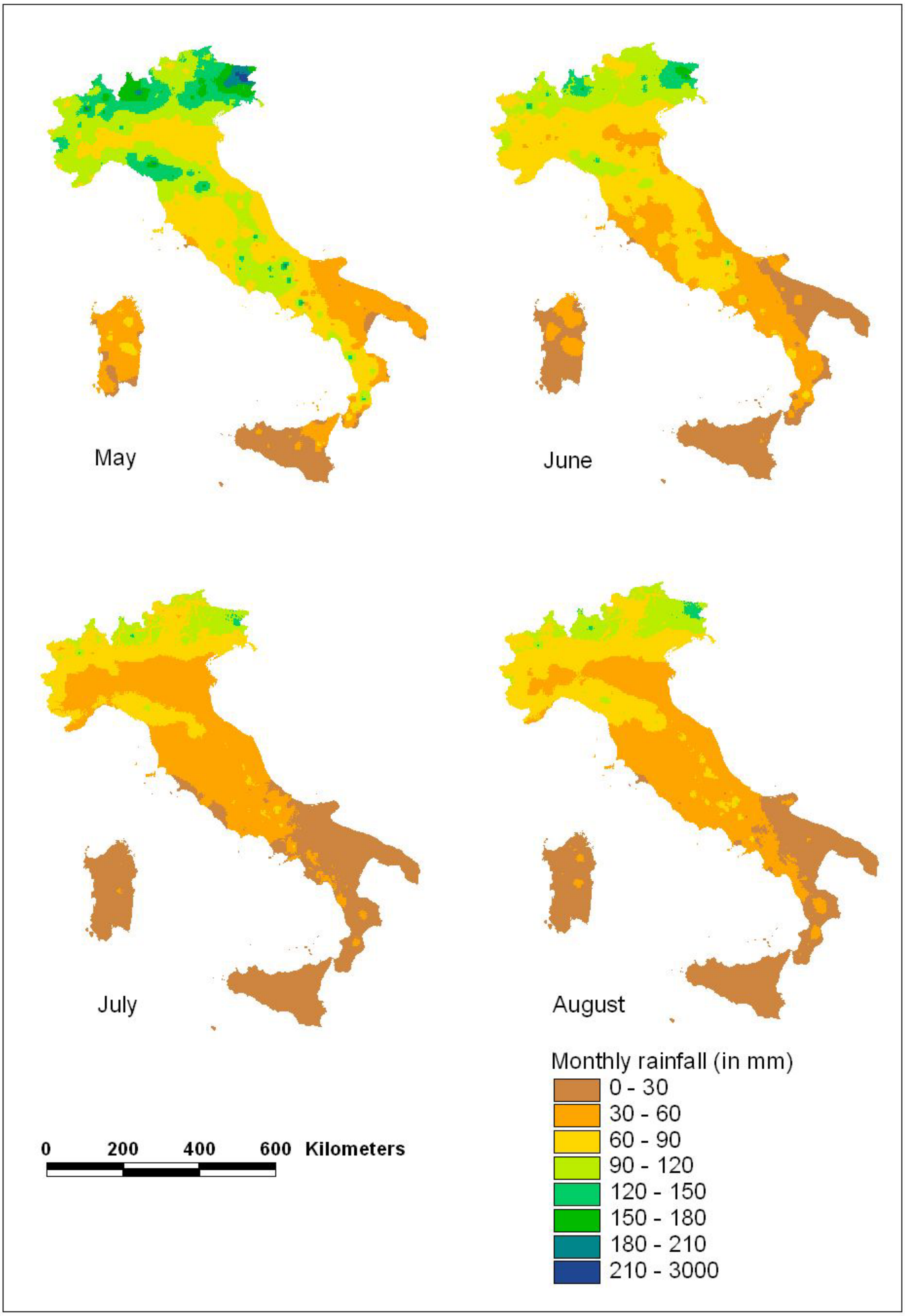

Figure 8: Monthly rainfall (mm) May to August

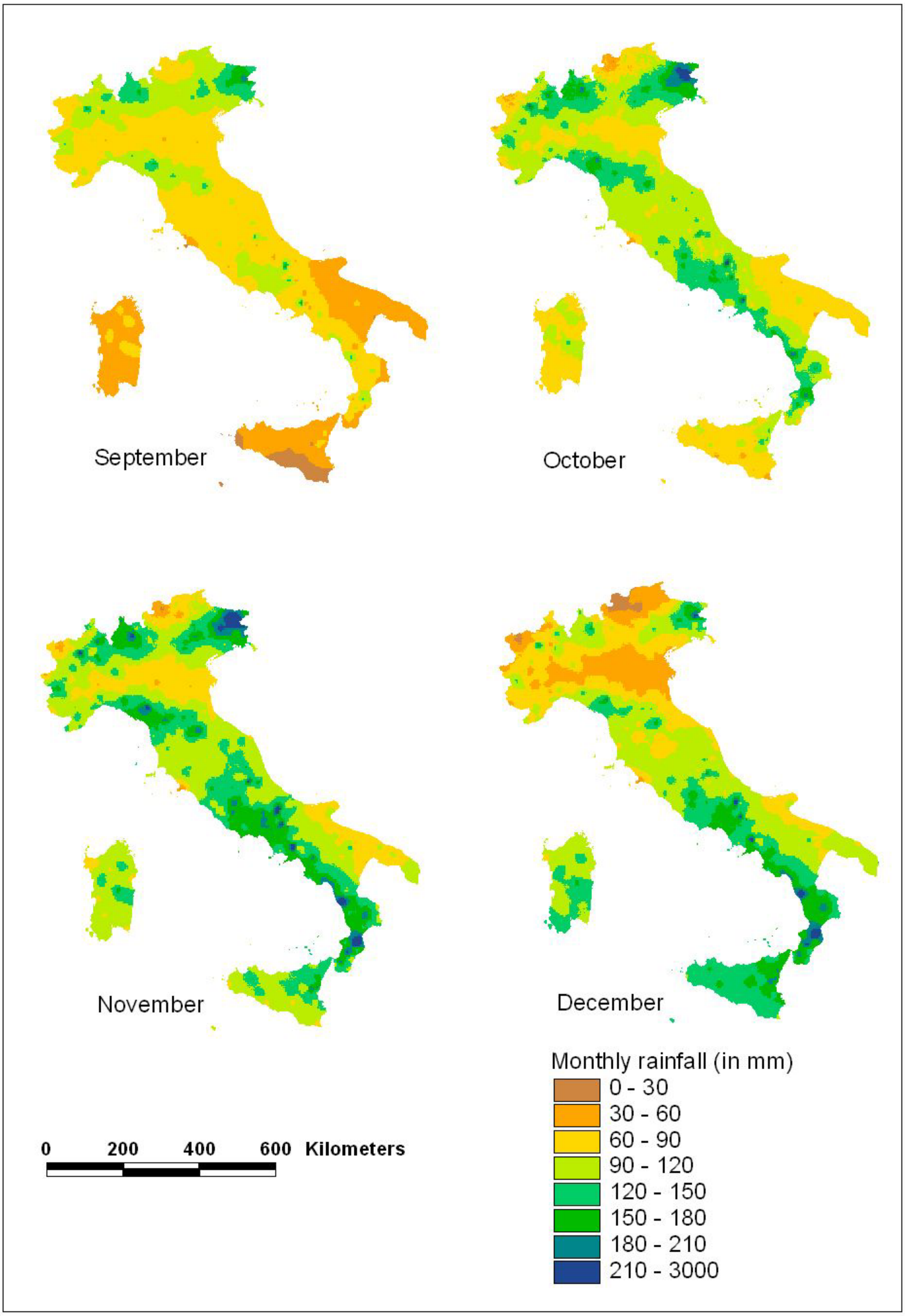

Figure 9: Monthly rainfall (mm) September to December

The average monthly rainfall for Italy was determined by applying equation 1.2 using a pixel size of 250m x 250m (Figures 7–9). This resolution was chosen because it corresponds to the pixel size of the DTM. The large variation in rainfall with height makes a larger pixel size less desirable, particularly in mountainous areas. It is clear that, for the same latitude, the precipitation in mountainous areas exceeds that in the lowlands. Moreover the precipitation is greater during summer in the northern part of Italy whereas it is greater in the south during winter.

Van der Knijff *et al.* (1999, 2002) calculated the annual R-factor using the equation (1.2):

$$R = a \cdot P_j$$

Where:

P_j : Annual rainfall (mm)

a : Respectively Van der Knijff *et al.* (1999) = 1.3

Even with respect to regional and seasonal differences, the determination of the monthly R-factor was calculated using a standard value of 1.3 for a and applied to the average rainfall data for each month.

4 Modification of Erodibility incorporating Crusting Index

For this study, the dominant surface texture, derived by applying a pedo-transfer rule to the 1:1,000,000 Soil Geographical Database of Europe (SGDBE), was used to calculate the K-factor that is subsequently used to estimate soil erosion risk. In a parallel study to estimate soil erosion risk in Europe, empirical rules were defined by INRA, Orleans, to combine data on land use, soil crusting susceptibility, soil erodibility, relief, and meteorological data (Le Bissonnais, Pers Comm.).

Figure 10, shows the basic scheme designed by INRA for 'chaining' the various inputs. The black labelled terms show the input data taken from the SGDBE whereas the blue labelled terms show the results of combining these input data. The two soil parameters, for soil crusting and erodibility, were derived from soil type (Soil), the dominant and secondary surface texture classes (Text1 and Text2 respectively), and parent material (Mat).

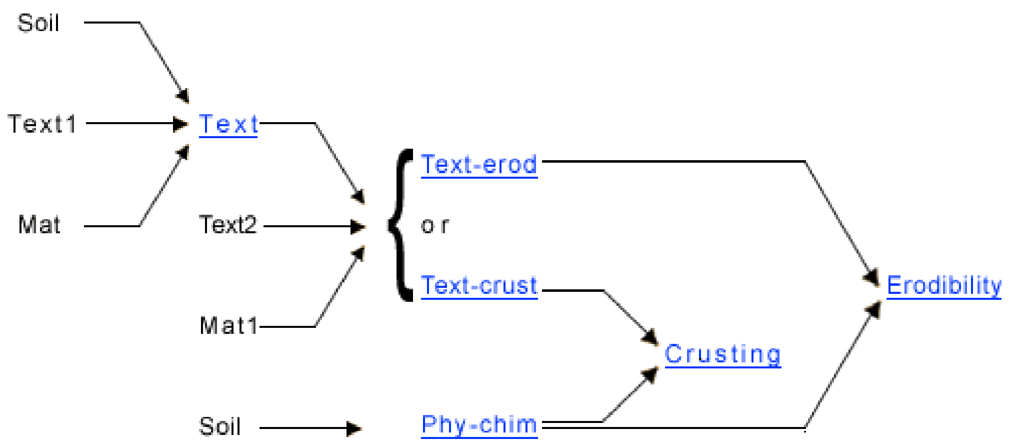

Figure 10: Chaining of data from the SGDBE (After Le Bissonnais, 1998)

The approach adopted here essentially combines the K-factor calculated by Van der Knijff *et al.* (1999, 2002) with the Crusting Index (CI) to estimate a new K-factor. The CI describes qualitatively how much the soil is prone to crusting. The higher CI, the greater the likelihood of the soil to form a surface-crust. Crusting restricts the infiltration of water into the subsoil. This greatly reduces the storage capacity of dry soil and is likely to significantly increase the runoff of surface water. Subsequently this allows separation and removal of soil particles. Figure 11 shows surface crusting of soil following heavy rain and this event caused significant sediment loss. Fine soil material was washed away leaving only the larger soil particles in the rills.

To produce a new data layer for the soil erodibility, the two existing data layers, the K-factor and the CI, had to be combined. The problem to be resolved was that on the one hand the USLE requires a quantitative parameter (USLE K-factor) and on the other hand the Crusting Index is essentially a qualitative parameter.

For example, CI=5 indicates a strong tendency for the soil to form a crust on the surface but there is no mechanism to assess how much sediment loss this could cause. Furthermore for CI=4, is this likely to lead to a loss of 4 four times as much sediment as for CI=1? This is not defined in the CI scheme and such assumptions cannot be made.

Figure 11: Soil loss and surface crusting after a heavy rain storm in North Italy (Varese, Lombardia, Italy), April 2002

To solve this problem for any value (1 to 5) of the Crusting Index, a factor was allocated to each CI value to express the relative influence on soil erosion. The assumption in assigning this factor is that, if the soil has a strong tendency to crust, then this will increase the amount of soil loss; i.e. the K factor will be larger, .

The following algorithm was used for CI:

If CI = 1 (very weak) … Then CK = 0.75K
If CI = 2 (Weak) … Then CK = 0.85K
If CI = 3 (Moderate) … Then CK = K
If CI = 4 (Strong) … Then CK = 1.15K
If CI = 5 (Very strong) … Then CK = 1.25K

Where:

K	=	K-factor
CI	=	Crusting Index
CK	=	Crusting-K-factor (incorporating CI)

These factors are essentially arbitrary and could be modified in future analyses.

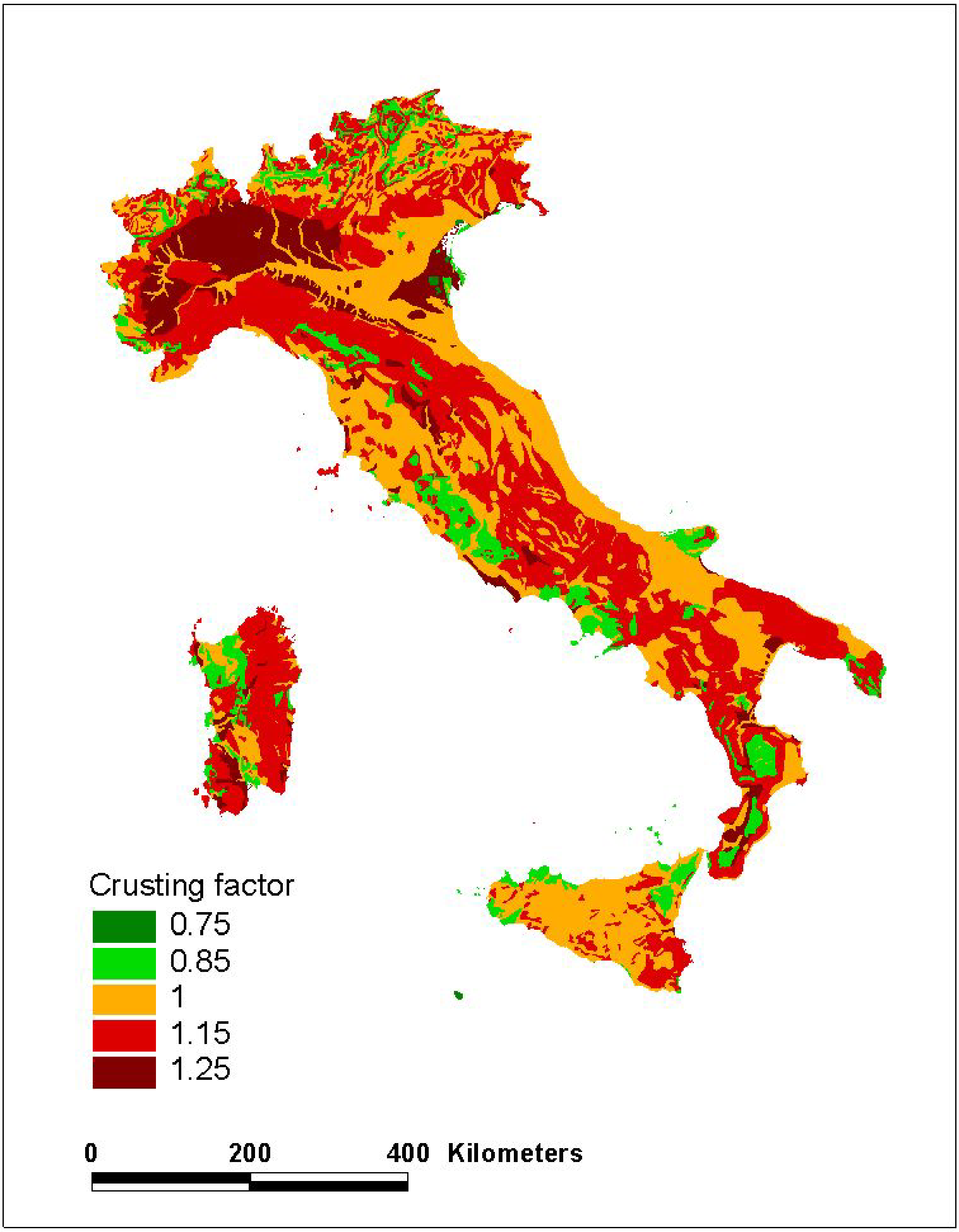

Figure 12: Crusting factor

The 250m pixel values of the two layers – CI and K-factor (determined by Van der Knijff *et al.*, 1999) were simply multiplied together to form a new erodibility parameter, the crusting-K-factor (CK), using the algorithm shown above.

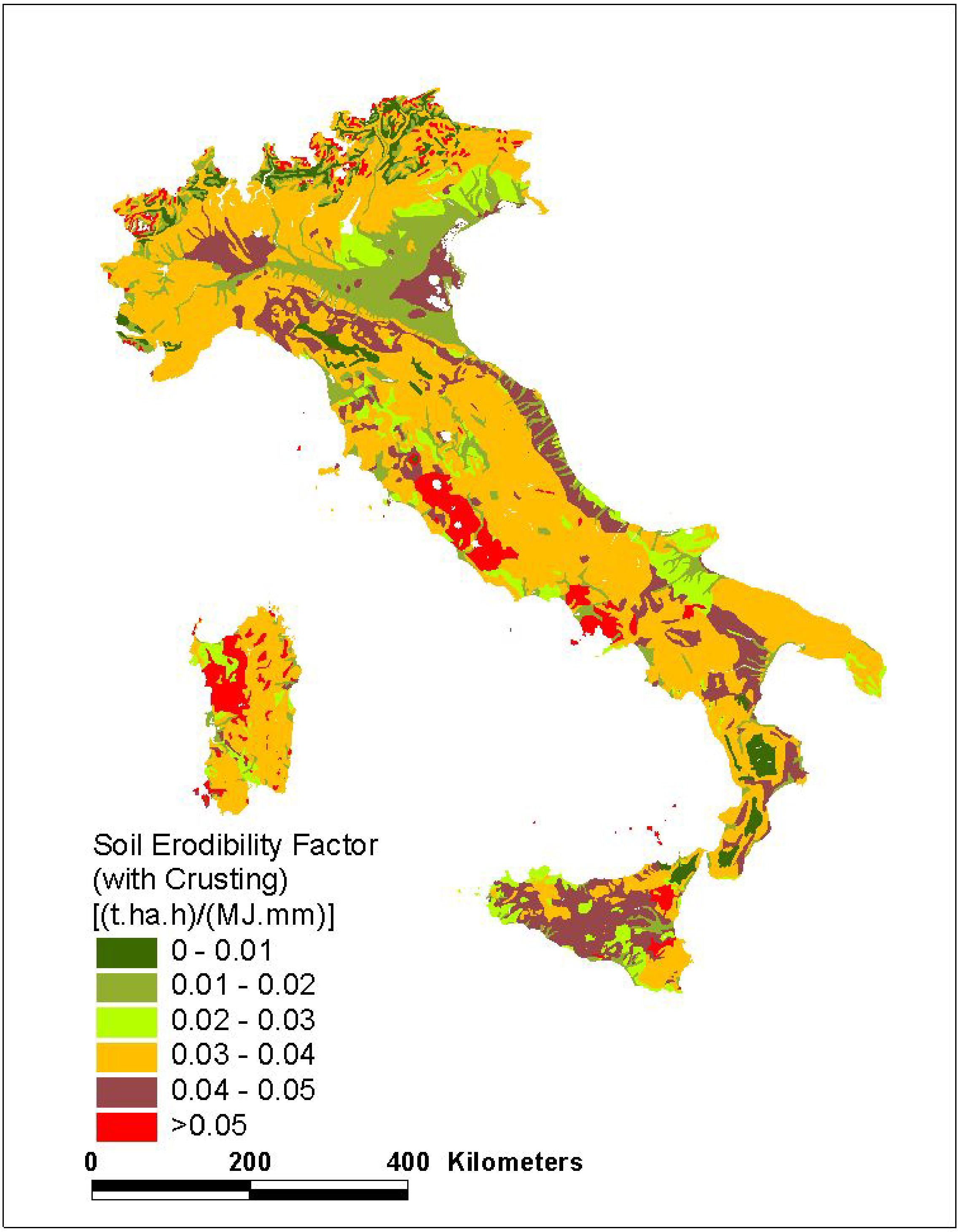

Figure 13: Crusting K-factor

Figure 12 shows the corresponding factors of the CI for Italy (for a pixel size of 250m). For pixels with a Crusting Index of 3, the K-factor remained unchanged. The factor assigned increases with the Crusting Index and decreases respectively as the Crusting Index becomes smaller. The new Crusting K-factor (Figure 13) was then used in the computation of new soil loss estimates, using the USLE in the same way as Van der Knijff *et al.* (1999, 2002).

5 Revised estimates of soil loss

The USLE (equation 1.1) was therefore applied again to the data sets for Italy, using the two modifed factors R and K, the other factors, the slope length factor (L), the slope factor (S) and the cover management factor (C), remaining unchanged.

New seasonal erosion risk assessments (aggregated from monthly estimates) for Italy, expressed in t/ha/year, are shown in Figure 14. The revised annual erosion risk in Italy is shown in Figure 15.

The differences between the annual erosion risk assessments estimated by Van der Knijff *et al*.(1999, 2002) – see Figure 4, and the revised assessments using the modified R- and K-factors – see Figure 15, are highlighted in Figure 16. The estimated annual soil losses in the mountainous area (Alps and Apennines) are larger using the modified R- and K-factors. The impact of using the new R-factor is greater because of the considerable variation of rainfall with altitude. The modified K-factor has a smaller effect on estimated soil loss because the crusting-K factor (CK) derives from a relatively small correction (0.75 to 1.25) applied to the original K factor.

In Figure 17, revised potential soil losses, expressed in t/ha/yr are shown. For the potential soil erosion risk it is assumed that there is no protecting soil cover and a value of 1.0 for the cover management factor (C-factor) is used in equation 1.1.

There are many models in existence estimating soil erosion. The USLE has the advantage of being less data demanding than plot models such EUROCEM. There is still much scope for improving assessments of soil erosion risk in Italy by applying the USLE-model to better data sets. The calculation of the R-factor could be further improved by accessing long-term rainfall totals. The K-factor could be improved with more accurate information on soil texture and organic matter.

More accurate L- and S-factors (Slope length and Slope angle) could be calculated using a finer scale DEM, e.g at 50m x 50m. The benefits would be greatest in mountainous areas, where the risk of soil loss is highest. However, although fine resolution DEMs exist, they are generally much too expensive for environmental researchers to use in their studies.

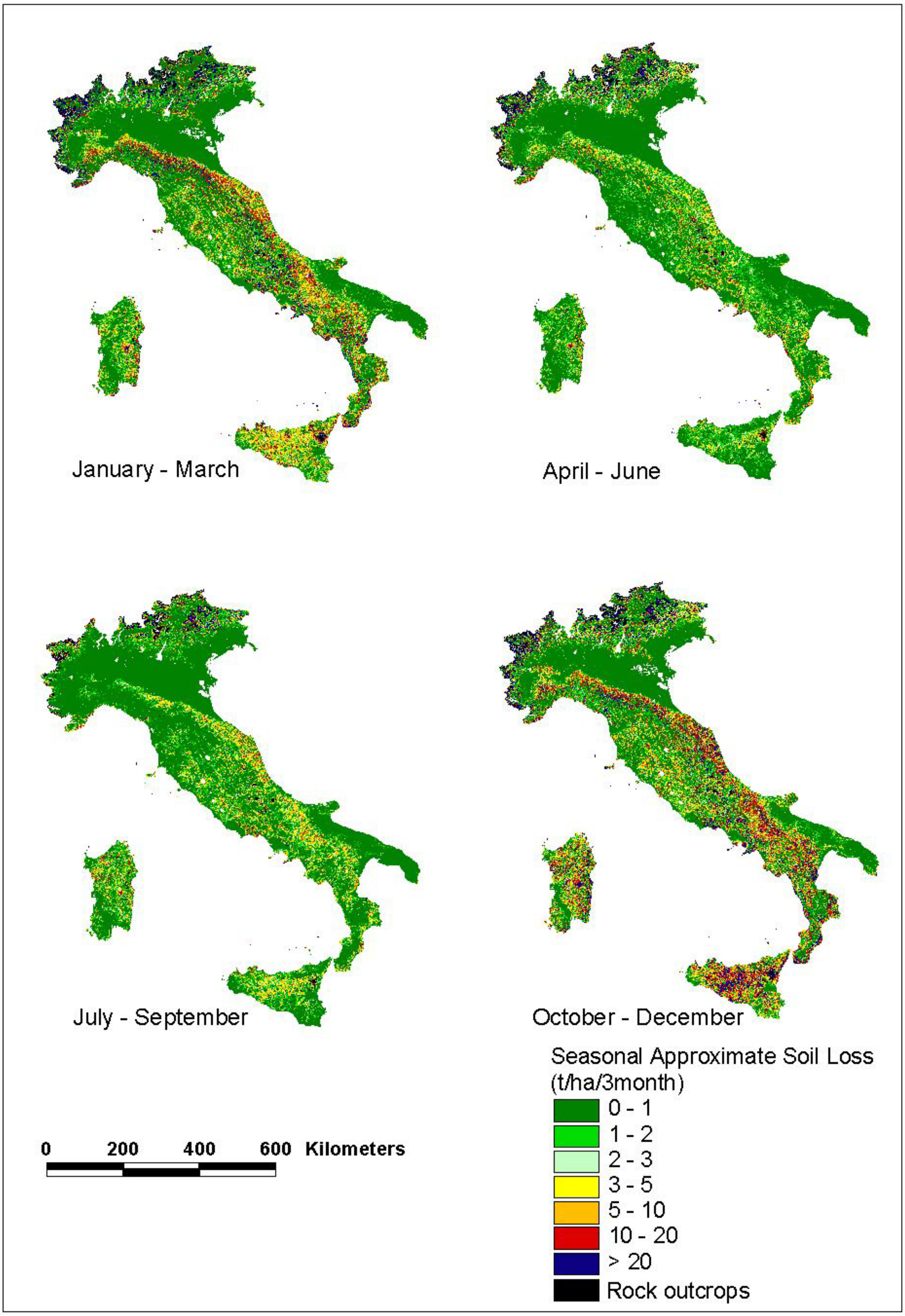

Figure 14: Seasonal erosion risk in Italy

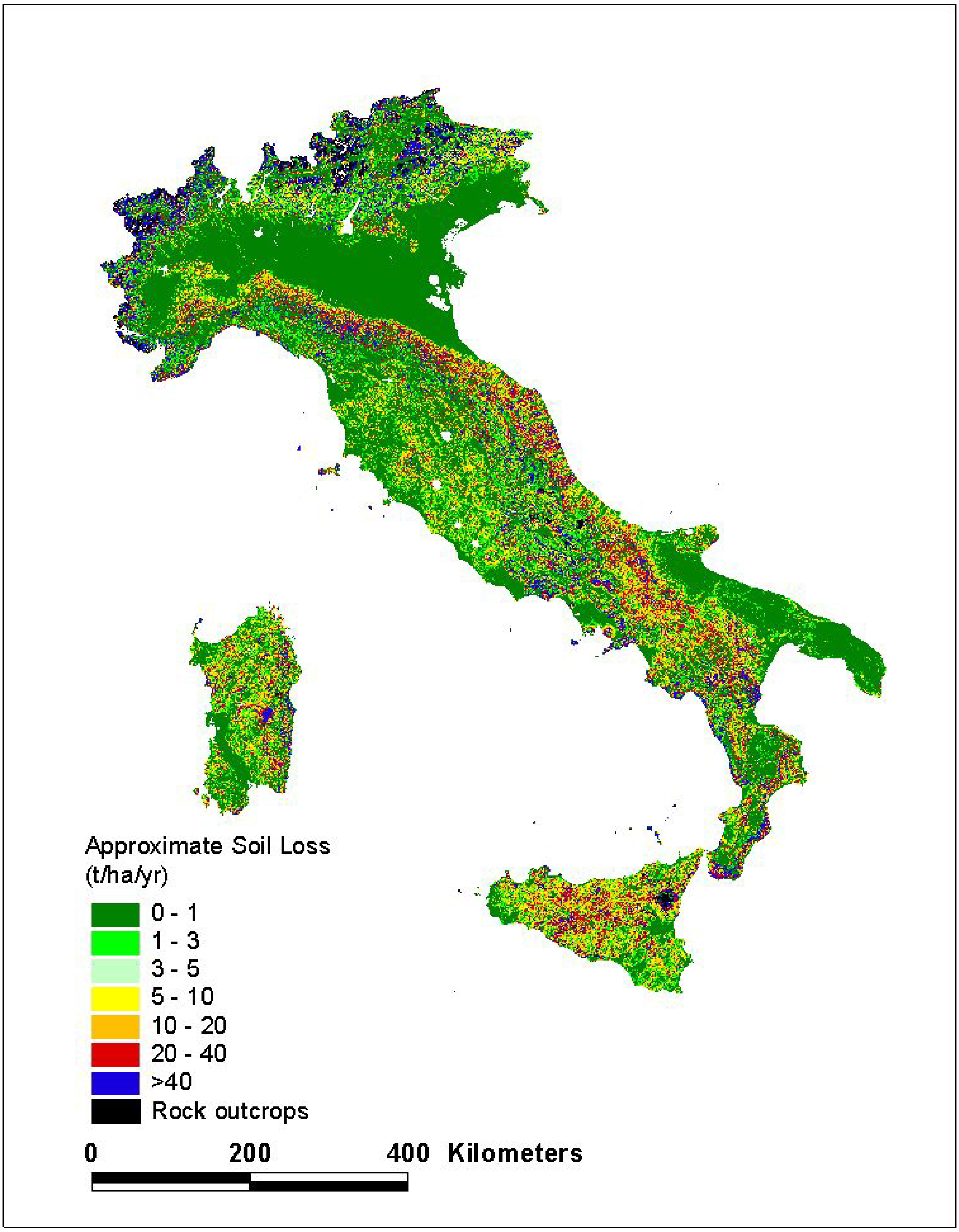

Figure 15: Annual erosion risk in Italy

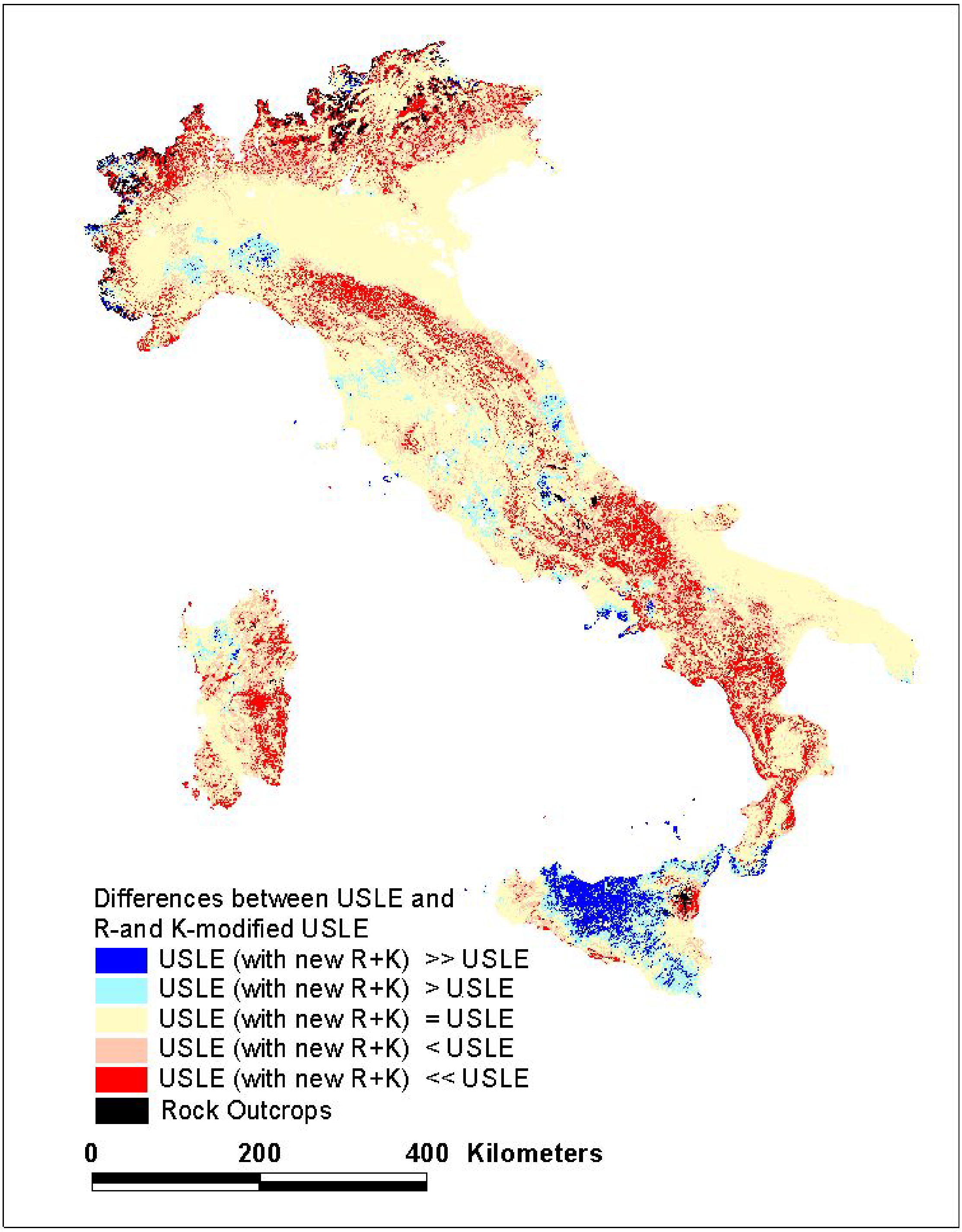

Figure 16: Differences between USLE and R-andK-modified USLE

Where ">>" stands for a difference bigger than $5t \cdot ha^{-1} \cdot yr^{-1}$

">" for a difference between *1* and $5t \cdot ha^{-1} \cdot yr^{-1}$

"=" for a difference smaller than $1t \cdot ha^{-1} \cdot yr^{-1}$.

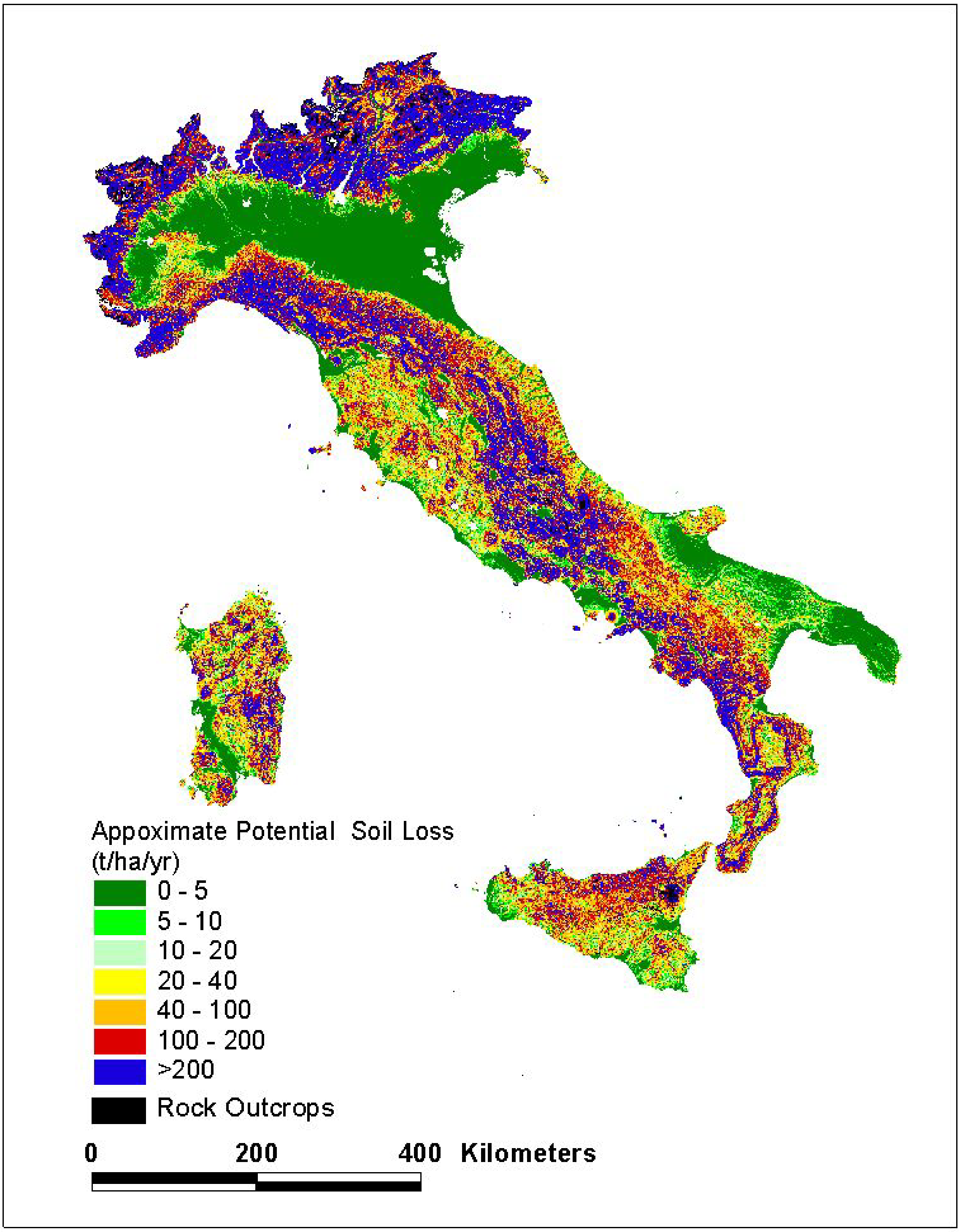

Figure 17: Potential annual erosion risk in Italy

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The mission of the Institute of Environment and Sustainability is to provide scientific and technical support to EU strategies for the protection of the environment and sustainable development. Employing an integrated approach to the investigation of air, water and soil contaminants, its goals are sustainable management of water resources, protection and maintenance of drinking waters, good functioning of aquatic ecosystems and good ecological quality of surface waters.

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