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Soil erosion in the Alpine area: risk assessment and climate change

Claudio BOSCO*, Ezio RUSCO, Luca MONTANARELLA & Panagiotis PANAGOS

European Commission, DG Joint Research Centre, Institute for Environment and Sustainability, Land Management and Natural Hazards Unit, Via E. Fermi 2749, Ispra, Italy
*Corresponding author e-mail: *claudio.bosco@jrc.it*

SUMMARY - *Soil erosion in the Alpine area: risk assessment and climate change* - Objective of the research is to define the magnitude of the Actual Soil Erosion Risk in the Alpine area and to link it with a perspective of medium long terms in relation to climate change. The Revised Universal Soil Loss Equation (RUSLE) was applied to the whole Alpine space. It allowed to produce, with a spatial resolution of 100 m, the map of actual soil erosion and two further maps defining soil erosion rates in A2 and B2 scenarios of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2001). This analysis was carried out by means of the dataset the International Centre for Theoretical Physics (ICTP) of Trieste. It provided daily rainfall values for the years 1960-1990 and for the IPCC A2 and B2 scenario 2070-2100. From a comparison between actual erosion and soil losses in A2 and B2 scenarios, it comes out that our model does not show relevant raises in erosion rates. However, low variations in soil losses rates is observable. In particular, B2 scenario shows a growth of low entity of soil losses over a significant part of the Alpine space. In A2 scenario a clear distinction between northern and southern Alps comes out. The northern part should experience a low reduction of soil erosion, whilst in southern areas a rise of soil losses should take place.

RIASSUNTO - *Erosione del suolo nell'area alpina: valutazione del rischio e cambiamenti climatici* - Il principale obiettivo del presente lavoro è di fornire una stima attuale dell'erosione del suolo in ambiente alpino e al contempo collegarla con i possibili sviluppi a medio-lungo termine indotti dai cambiamenti climatici. È stata quindi applicata a tutto l'arco alpino la versione riveduta dell'equazione universale di perdita di suolo (RUSLE). Ciò ha permesso di produrre, ad una risoluzione spaziale di 100 m, la mappa dell'erosione del suolo nelle Alpi e due ulteriori mappe relative alle previsioni di erosione del suolo negli scenari A2 e B2 dell'Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2001). Questa analisi è stata condotta grazie ai dati forniti dall'International Centre for Theoretical Physics (ICTP) di Trieste. I dati consistono in stime di precipitazione giornaliere per gli anni 1960-1990 e per gli scenari A2 e B2 2070-2100 dell'IPCC. Da un confronto tra l'erosione attuale e le previsioni relative a questi due scenari non emergono rilevanti incrementi di erosione del suolo, sebbene si evidenzi un leggero incremento del fenomeno. In particolare, lo scenario B2 evidenzia un generale lieve aumento dell'erosione del suolo su di un'area significativa del territorio alpino, mentre nello scenario A2 emerge una netta distinzione tra nord e sud delle Alpi: la parte più a nord appare caratterizzata da una generale riduzione dei fenomeni erosivi (seppure di lieve entità) che invece mostrano un leggero incremento nella parte meridionale dell'arco alpino.

Key word: Alps, soil erosion, climate change
Parola chiave: Alpi, erosione, cambiamento climatico

1. INTRODUCTION

Soil erosion is the wearing away of the land surface by physical forces such as rainfall, flowing water, wind, ice, temperature change, gravity or other natural or anthropogenic agents that abrade, detach and remove soil or geological material from one point on the earth's surface to be deposited elsewhere. Soil erosion is a natural process that can be exacerbated by human activities.

Soil erosion is increasing in Europe. Precise erosion estimates are not possible due to the lack of comparable data, therefore it is difficult to assess the total area of the EU affected by erosion[1].

Soil erosion is a matter of primary importance in mountain areas. Increasing numbers of tourists, changes in farming/cultivation techniques and climate change are expected to intensify soil erosion in the Alps.

The loss of soil from a field, the breakdown of soil structure, the decline in organic matter and nutrient, the reduction of the available soil moisture as well as the reduced capacity of rivers and the enhanced risk of flooding and landslides are processes linked with soil erosion. In all regions with steep relief and at least occasional rainfall, debris flows occur in addition to surface erosion processes.

These aspects are clearly addressed and identified in the "Action Plan on Climate change in the Alps" where it is clearly statement that "the effect of global warming in Alpine area is three times higher than the world average. These effects also involved in a densely populated area (14 million of inhabitants) and very touristy, which justifies an effort. In respect of climate change, the mountain with the

[1] SEC(2006)620 Impact assessment of COM (2006) 232 Soil strategy.

content of water resources and the wealth of biodiversity hold a particular role to play towards other areas. Their preservation is therefore supranational importance”[2].

The analysis of the existing studies on the topic highlights that the main research methodologies have been developed to study erosion in agricultural contexts or hill areas with a mild climate. Therefore, it is difficult to apply these methods in mountain areas, also because of the extreme complexity of the alpine system.

For this reason, some researchers assert that the most common soil erosion models, as USLE/RUSLE or CORINE EROSION, can not be efficiently applied in an Alpine environment, because they were designed to be used on hilly agricultural areas where sheet and rill erosion processes are prevailing. Furthermore, the above mentioned models are not designed to consider some typical erosion processes of alpine areas as, for example, the debris flows.

An efficient model to analyze the real morpho-sedimental processes should in theory be able to

- minimize empirical factors and be based mainly on physically based factors;
- use strong calculation methods;
- combine all factors involved in the process.

A step forward has been made in this direction with the introduction of new-generation models, as i.e. PESERA (Pan European Soil Erosion Risk Assessment: Kirkby M.J. *et al.* 2004).

However, as regards the research related to erosion and, in this case, Alpine areas erosion, the most used model is USLE (in one of its different versions: i.e. USLE, RUSLE).

As a matter of fact, it is the only model in which input data can be obtained in different ways (measurement, estimation, interpolation).

Advanced models, as Water Erosion Prediction Project (WEPP, Flanagan 1995), have been and still are less used, because they are often less flexible to be adapted to situations that have not already been parameterized before. Furthermore, USLE is a model used on differentiated spatial scales.

Another advantage in the use of RUSLE is related to its flexibility, as it is always possible to set this equation to adapt it to the environment to be analysed.

On the basis of the above mentioned considerations RUSLE model has been used in the present research. The main reason of this choice is that RUSLE has a more flexible data processing system. A further reason is the acquired experience in the application of RUSLE both on local and continental scale. On the contrary, it is useful to highlight that, as already mentioned, the RUSLE model has been designed mainly for agricultural terrains. Its application in Alpine areas could hence lead to a coarse estimation, from a quantitative point of view, of water erosion processes. However, it is necessary to take into account that our main objective is the assessment of the soil erosion in relation to climate change.

2. STUDY AREA

The study area is represented by the countries parties of the Alpine Convention, as show in the figure 1. The Alpine total area is more than 25 million of hectares. The geomorphology of the Alps is characterized by steep slopes (with a mean of about 30%) and altitudes ranging from 0 to more than 4800 meters (Mont Blanc with 4810 meters is the highest mountain), with an average peak height of approximately 1000 meters.

3. METHODOLOGY

3.1. *Input data and factors*

RUSLE estimates erosion by means of an empirical equation:

$$A = R \times K \times L \times S \times C \times P \quad (1)$$

where: A= (annual) soil loss (t ha^{-1} yr^{-1}); R= rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}); K= soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}); L= slope length factor (dimensionless); S= slope factor (dimensionless); C= cover management factor (dimensionless); P= human practices aimed at erosion control (dimensionless).

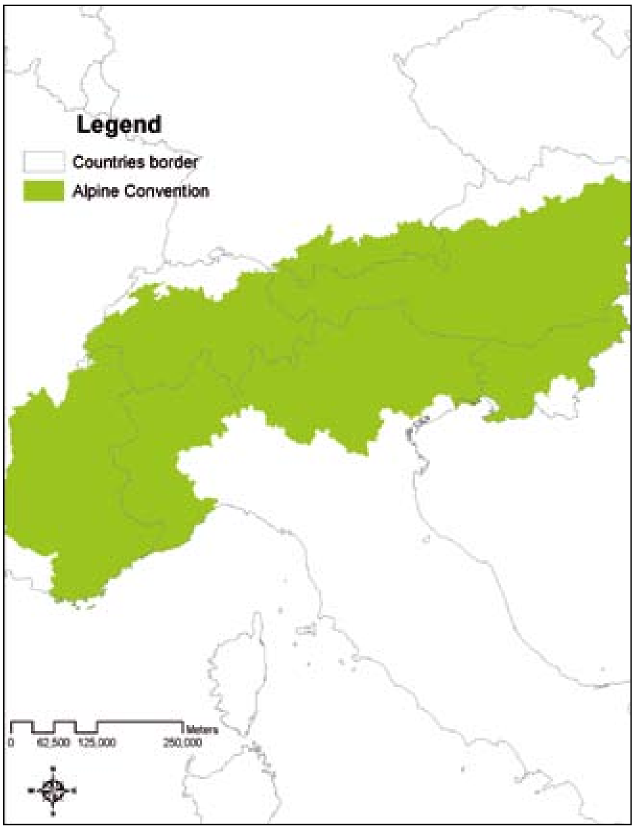

Fig. 1 - Study area.
Fig. 1 - Area di studio.

[2] “Action Plan on Climate change in the Alps” adopted by Parties of the Conference of the Alps on 12th March 2009 at the 10th session of the Alpine Conference.

As spatial information regarding human practices aimed at protecting soil from erosion was not available, the P factor was set 1 and, actually, it has not considered.

3.2. Rainfall-runoff

The RUSLE rainfall erosivity factor (R) indicates the climatic influence on the erosion phenomenon through the mixed effect of rainfall action and superficial runoff. The R factor for any given period is obtained by summing, for each rainstorm, the product of total storm energy (E) and the maximum 30 minutes intensity (I_{30}) (Wischmeier 1959). Unfortunately, these data are rarely available at standard meteorological stations.

The rainfall erosivity factor probably is, among the different components of the soil loss equation, one of the most difficult to derive, above all because rainfall data with adequate high temporal resolution are very difficult to obtain over large areas. Rainfall data we could collect are not enough detailed to apply Wischmeier's procedure to compute R factor over the whole alpine space.

This is the reason because simplified formulas, with lower temporal resolution, were applied.

There are limited applications of these formulas at the Alpine level and there is no consensus on which are the most appropriate algorithms to determine R factor instead of the EI_{30} in the Alpine zone.

Hence, a statistical analysis was carried out to estimate the degree of correlation (Correlation Coefficient [R^2] and Root Mean Square Error [RMSE]) between R factor values computed by means of EI_{30} or using the most commonly used simplified formulas (Arnoldus 1980; Arnoldus 1977; Renard & Freimund 1994; Lo *et al.* 1985; Yu & Rosewelt 1996; Ferrari *et al.* 2005). The analysis was carried out on rainfall data with high temporal resolution available for 42 meteorological stations in Veneto region, inside the Alpine territory. Data were supplied by ARPAV (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto).

With the aim of computing the correlation between the simplified formulas and Wischmeier's R factor, Pearson (r) correlation coefficient was used.

Looking at data distribution (Fig. 2), it comes out that all simplified formulas analysed over or under-estimate R factor. Among all the other, with growing over or under-estimations at higher R values, Lo *et al.* (1985) equation shows a systematic over-estimation. The Lo *et al.* formula shows the highest R^2 and among the lowest RMSE values. Compared to Lo's equation, Arnoldus (1980) formula, that is the wide used equation, shows a lower RMSE value but its R^2 is inferior and its trend inconstant: the higher are R (EI_{30}) values, the higher are the errors. The maximum error caused by Arnoldus is higher than the one using Lo's equation.

We decided hence to apply the Lo *et al.* equation to calculate the R factor of the RUSLE. Ideally, none of the formulas we tested can be considered suitable for a quantitative estimation of erosion on the Alpine territory. Unfortunately, the lack of data with adequate resolution got us to apply the best one among them.

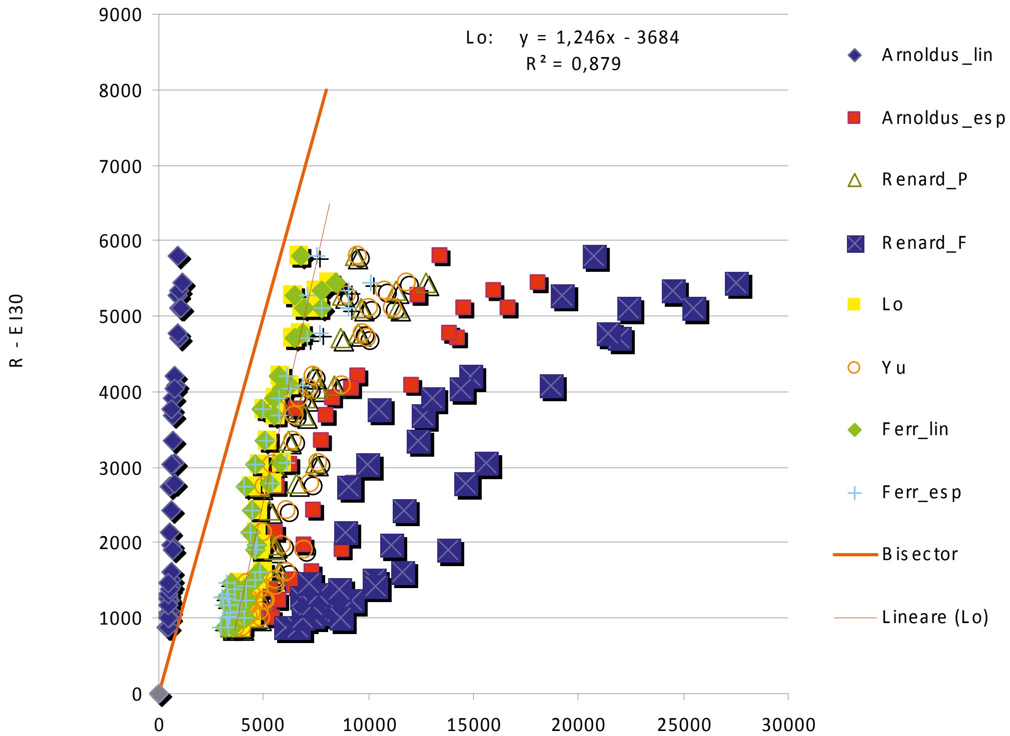

Fig. 2 - Comparison between R factor values obtained with EI30 method and simplified formulas.
Fig. 2 - Confronto tra il fattore R calcolato utilizzando l'EI30 ed ottenuto tramite l'utilizzo di formule semplificate.

The rainfall measurement data we used to determine rainfall erosivity factor on the whole Alpine space have been provided by the International Centre for Theoretical Physics (ICTP) of Trieste. These data are the output of a prevision model of the climatic change (RegCM, Regional Climate Model), that provides the daily rainfall values for the years 1960-1990 and for the IPCC A2 e B2 (2070-2100) scenarios. RegCM is a 3-dimensional, sigma-coordinate, primitive equation regional climate model. Version 3 is the latest release. The use of climatic modeled data rather than measured data has allowed the data processing in a similar manner for the whole study area and comparison with the modeled climatic data with time series 2070-2100.

3.3. Soil erodibility

The soil erodibility factor K indicates the susceptibility of soils to erosion. It is defined as the unit erosion index for the R factor in relation to a standard fallow parcel (22.13 m length; 9% slope). On this basis, the value of factors such as length, slope, cultivation and anti-erosion actions becomes unitary. K is usually estimated using the normograph and formulae that are published in Wischmeier & Smith (1978). While these equations are suitable for large parts of USA, they are not ideally suited for European conditions. Romkens *et al.* (1986) performed a regression analysis on a world-wide dataset of all measured K-values, from which the following equation was derived (revised in Renard *et al.* 1997). The equation is based on soil particle size distribution (soil texture).

Information on soil surface texture were derived from the 1:1.000.000 Soil Geographical Database of Europe (ESGDB) (Heineke *et al.* 1998).

3.4. Slope and length

The main innovation of the RUSLE model, in comparison with the original model (USLE), is the LS factor. The factor considers the flows convergence and is the result of the combination of the slope (S) and length (L) factors. Many methods have been proposed to improve the calculation of the topographic factor LS, but just in the last ten years a certain accuracy has been reached thanks to the implementation of GIS systems and of digital elevation model (DEM). The L Factor has been substituted by the Upslope Contributing Area (UCA) (Moore & Burch 1986; Desmet & Govers 1996), in order to consider the convergence and divergence of the superficial runoff. The UCA area is where water flows in a given cell of the grid. L and S factors have been determined through GIS procedures carried out using the following relation of Moore & Burch (1986).

For the calculation of the LS factor the DEM SRTM (Shuttle Radar Topography Mission) has been used. The resolution of the DEM is of 90 m.

3.5. Soil cover management

The soil cover factor represents the influence on soil loss of vegetation. The C factor represents the relation between the soil loss in certain agricultural or cover condi-

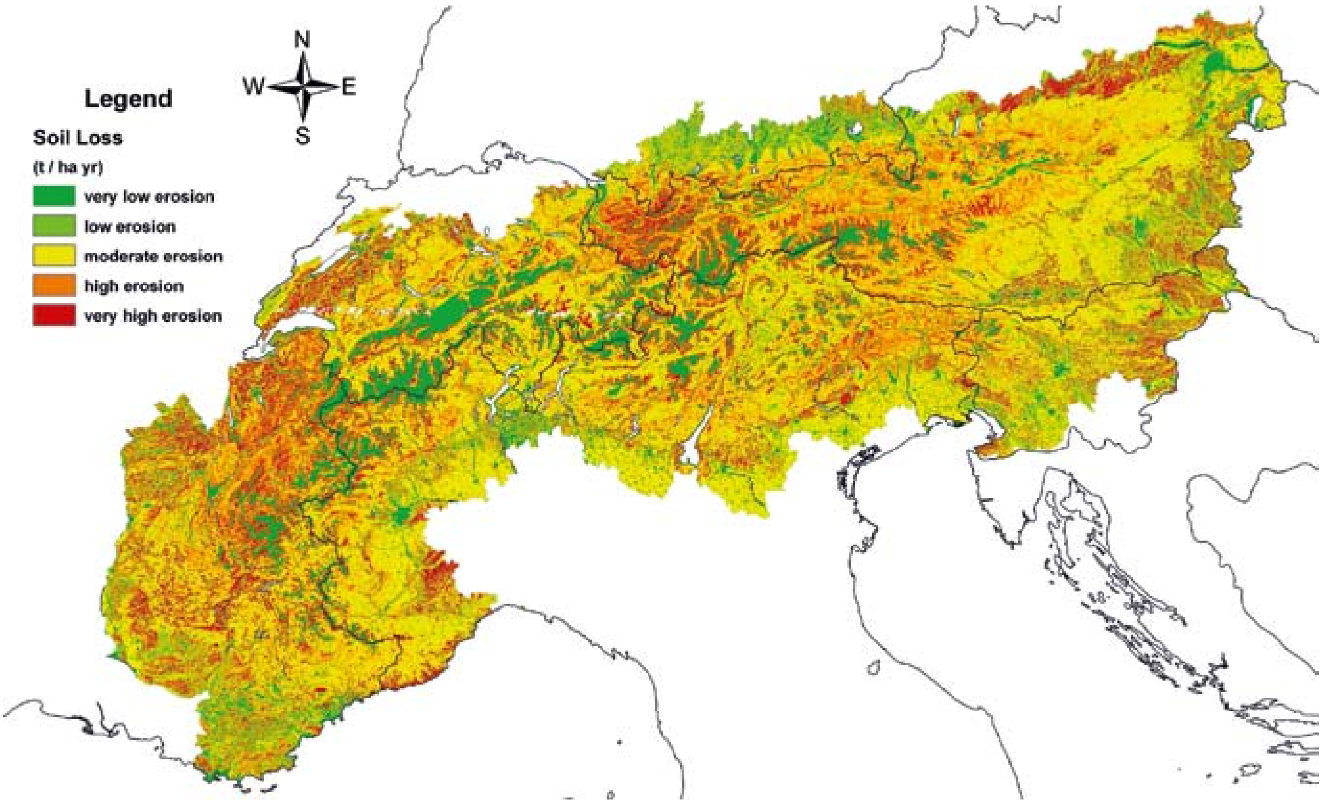

Fig. 3 - Erosion map (t ha^{-1} yr^{-1}).
Fig. 3 - Mappa dell'erosione del suolo (t ha^{-1} yr^{-1}).

tions and the erosion that would be obtained from a standard fallow parcel (bare soil). The evaluation of this factor is difficult, because it always depends on changes in terms of environment, cultivations, agricultural activities, residuals management and on the phenology of the plant in the year. The C factor for a certain soil cover typology may have different values. Due to the lack of detailed information and to the difficulties in processing all factors on a large scale, it is difficult to use RUSLE guidelines to estimate the soil cover parameter. Therefore, the average values of literature have been used for this aim (Suri 2002; Wischmeier & Smith 1978). The necessary data to establish the C parameter have been provided by the Corine Lan Cover project, a European programme aimed at reproducing maps about soil use, analysing the image of the whole Europe provided by satellite. The calculation of the soil cover factor has been processed using the information layer Corine Land Cover 2000 (CLC 2000) third level. The information layer CLC 2000 is not available for the Switzerland. For this area the CLC 1990 has been used. Unfortunately, the hierarchy of the land cover classes and related legends for Swiss CLC 1990 is different from the rest of the Alpine territory. Hence, an intervention aimed at uniforming the data was necessary. To this aim, everything has been traced to the 44 classes of soil use/cover established in the CLC 2000. A C factor value has been assigned to every class, based on literature data.

4. RESULTS AND DISCUSSION

The results of the applied model are expressed as tons/hectares/years (t ha^{-1} yr^{-1}). As already mentioned due to a systematic overestimation of the R factor, calculated using the Lo's formula, a qualitative reclassification of the values of soil erosion in 5 classes has been performed.

By analyzing erosion values obtained with RUSLE application (1960-1990), it is evident that the Alpine territory is subject to erosion phenomena. According to the classification we adopted, about 20% of the Alpine space shows rather high erosion; nearly 30% shows a middle risk and the remaining 50% a low risk. Nevertheless, due to the extension of the Alpine space it is necessary to carry out a more detailed analysis, linked with geo-litho-morphologic and land use/cover parameters. As it has been previously pointed out, slopes, slope length, pluviometric regime and soil cover play a crucial role in the erosive process. The study area was hence subdivided in some classes of landscapes, with the altitude acting as discriminating agent. Elevation shows, at least in the Alps, strong correlations with the other factors previously mentioned. The Alpine space was therefore subdivided into four elevation zones:

- flat areas (< 300 m a.s.l.)
- hill areas (300-600 m a.s.l.)
- mountain areas (600-2000 m a.s.l.)
- high mountain areas (> 2000 m a.s.l.).

By analyzing the data relative to the elevation zones it is possible to highlight the relative significance of the different factors of the model.

- In the areas below 300 m a.s.l., more than the 80% of the territory shows low or moderate erosion, but the remaining 20% is characterized by high or very high erosion rates. The observation of the C factor map allows understanding that in these areas the role of cover vegetation is low, because the most of these areas are represented by arable land.
- At higher altitudes (300-600 m a.s.l.), the proportion of territory with an erosion rate low or moderate diminishes, whilst nearly 20% of the zone shows a very high erosion rate. This trend is caused by an increase in slopes which produces very high risk levels in areas with poor cover. On the other hand, the presence of wooded areas contributes in keeping high the percentage of territory with low risk level.
- In the mountain zone, (600-2000 m a.s.l.), the high percentage of forest cover (compared to the lower zones) leads to comparable levels of low or moderate erosion rates similar to that found at lover altitude and to a reduction in the areas with very high soil losses.
- In the high mountain zone, erosion presents a very particular trend. More than 40% of these areas is not subject to soil losses. Moreover, more than 30% of the remaining territories are interested by high or very high erosion rates. This is easy to explain taking into account the lithology of these areas: at these altitudes the soil is often very thin or bare rocks are present; but in the areas where soils exist, geo-morphologic characteristics, severe rainfalls and often lacking of vegetation cover make them very vulnerable.

After all, without further deepening the item, it is possible to assert that Alpine space is, due to its peculiarities, highly vulnerable to erosion risk. But the widespread presence of vegetation cover allows, in a significant part of the territory, to keep it under control and this is the reason because a right management of mountainous region cannot be disregarded.

Referring to the Soil Erosion Risk based on climatic data referred to A2 and B2 scenarios (2070-2100), the obtained results are compared with the actual erosion risk. The analysis allowed the definition of soil erosion trends in relation to different scenarios of climate change (Fig. 4). From the analysis some evaluations come out same considerations.

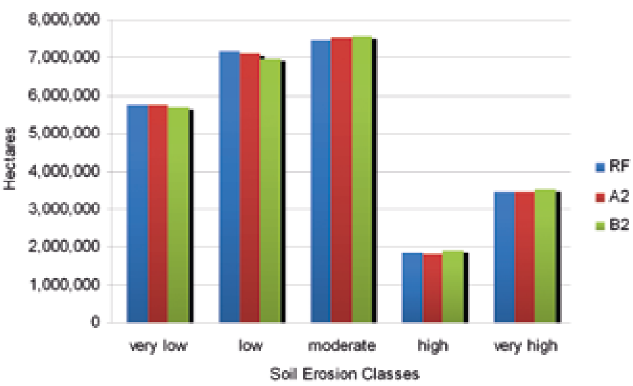

Fig. 4 - Spatial extension of soil erosion classes in the analysed scenarios.

Fig. 4 - Estensione spaziale delle classi di erosione del suolo negli scenari analizzati.

From a general comparison between actual soil erosion (1960-1990) and future soil losses (A2 and B2 scenarios: 2070-2100), it is evident that erosion rates remain nearly constant. The spatial extension of the soil erosion classes, in fact, is almost unvaried.

Some evidences arise from a spatial analysis of maps defining, for each grid cell, differences between actual erosion data and A2-B2 scenarios. B2 scenario shows a general growth of soil losses over a significant part of the Alpine space. The increase is, however, of low entity. From A2 scenario comes out, instead, a strong distinction between northern and southern Alps. The northern part should experience a low reduction of soil erosion, whilst in the southern areas a rise of soil losses should take place.

Ongoing climate change contributes to increase the spatial variability of rainfalls. They should decrease in subtropical areas and increase at high latitudes and in part of the tropical zones. The precise location of boundaries between regions of robust increase and decrease remains uncertain and this is commonly where atmosphere-ocean general circulation model (AOGCM) projections disagree. The Alps are located in this transitional zone. This is the reason because, as a consequence of the expected climate change, a very little variation in soil erosion rates over the Alpine space was predictable. RegCM model, which produced rainfall data used in this study, places the transition zone more southward in B2 than in A2 scenario. Due to this difference in the placement of the transition zone, even though A2 scenario foresees heavier climate change than other scenarios, the B2 scenario shows, over the Alps, higher rainfall rates. This is the reason because in B2 scenario a higher number of areas with high erosion are present. In A2 scenario, moreover, prevailing winds come from the south. This explains the sharp demarcation line between northern and southern Alps and the increase of rainfalls on the southern side. B2 scenario is characterized by a low increment in soil erosion rates, even if some isolated areas present an opposite trend, which is difficult to explain. The investigation of these phenomena requires further analysis, going beyond the aims of this study. They are possibly explainable from a modelling point of view and could be due to non linearity problems, easily coming out at these scales. To justify their origin several models should be used, with the aim of a deeper calibration of results. This is the reason because IPCC derived results of its four report on climate change making use of 20 climate models.

As mentioned before, soil erosion trends in the Alpine region are mainly attributable to changes in rainfall regimes. A better estimation of soil losses in climate change scenarios could be assured by evaluating future variations of cover management factor.

5. CONCLUSIONS

The application of RUSLE over the Alpine territory, moreover, presented huge difficulties mainly due to data availability problems. Unfortunately, there is not a set of data necessary for a strict application of the model and some algorithms have been forced into a simplification in order to adapt them to the data availability. It is the case of R and K factors. Particularly, the simplified equation used for R factor computation, though preferable to the other available, tends to over-estimate the measured rates of erosivity and makes scarcely meaningful a validation based on measured data.

These, and many other uncertainties, propagate throughout the model, resulting in an uncertainty in the estimated erosion rate. Despite these deficiencies and shortcomings, the methodology applied has produced valuable information on Alpine soil erosion processes and on their distribution. The spatial analysis, in fact, has allowed the identification of areas which are likely to experience significant erosion rates. More detailed input data and more sophisticated erosion models might warrant a better quantitative estimation of soil losses due to water erosion.

REFERENCES

Arnoldus H.M.J., 1977 - Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. *FAO Soils Bull*., 34: 39-51.

Arnoldus H.M.J., 1980 - An approximation of the rainfall factor in the Universal Soil Loss Equation. In: De Boodt and Gabriels: *Assessment of erosion.* FAO Land and Water Deveopment Division, Wiley & Sons, England: 127-132.

Desmet P.J.J. & Govers G., 1996 - A gis procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *J. Soil Wat. Cons*., 51: 427-433.

Ferrari R., Pasqui M., Bottai L., Esposito S. & Di Giuseppe E., 2005 - Assessment of soil erosion estimate based on a high temporal resolution rainfall dataset. In: Proc. 7th European Conference on Applications of Meteorology (ECAM), Utrecht, Netherlands, 12-16 September 2005.

Flanagan D.C. & Nearing M.A. (eds), 1995 - *USDA – Water erosion Prediction Project (WEPP): Hillslope profile and watershed model documentation.* USDA-ARS National Soil Erosion Research Laboratory, West Lafayette (NSERL Report No. 10).

Heineke H.J., Eckelmann W., Thomasson A.J., Jones R.J.A., Montanarella L. & Buckley B., 1998 - Land Information Systems: Developments for planning the sustainable use of land resources. Office for Official Publications of the European Communities, Luxembourg. EUR 17729 EN: 546 pp.

Kirkby M., Jones R.J.A., Irvine B., Gobin A., Govers G., Cerdan O., Van Rompaey A. J. J., Le Bissonnais Y., Daroussin J., King D., Montanarella L., Grimm M., Vieillefont V., Puigdefabregas J., Boer M., Kosmas C., Yassoglou N., Tsara M., Mantel S., Van Lynden G.J. & Huting J., 2004 - Pan-European soil erosion risk assessment: The PESERA MAP Version 1 October 2003. Explanation of: Special Publication ISPRA 2004, 73.

IPCC, 2001 - Climate Change 2001: The Scientific Basis. In: Houghton J.T., Ding Y., Griggs D.J., Noguer M., van der Linden P.J., Dai X., Maskell K. & Johnson C.A. (eds), *Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA: 881 pp.

IPCC, 2001 - Climate Change 2001: Synthesis Report. In: Watson R.T. & the Core Writing Team (eds), *Contribution of Working Groups I, II, and III to the Third Assessment Report of the Integovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA: 398 pp.

Lo A., El-Swaify S.A., Dangler E.W. & Shinshiro L., 1985 -

Effectiveness of EI30 as an erosivity index in Hawaii. In: El-Swaify S.A., Moldenhauer W.C. & Lo A. (eds), *Soil erosion and conservation.* Soil Conservation Society of America, Ankeny: 384-392.

Moore I. & Burch G., 1986a - Physical basis of the length-slope factor in the universal soil loss equation. *Soil Sci. Soc. Am. J.*, 50: 1294-1298.

Renard K.G. & Freimund, J.R., 1994 - Using monthly precipitation data to estimate the R-factor in the revised USLE. *Journ. Of Hydr.*, 157: 287-306.

Renard K.G., Foster G.R., Weessies G.A., McCool D.K. & Yoder D.C. (eds), 1997 - Predicting Soil Erosion by Water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). *U.S. Department of Agriculture, Agriculture Handbook*, 703: 404 pp.

Romkens M.J.M., Prased S.N. & Poesen J.W.A., 1986 - *Soil erodibility and properties*. In: Proceeding 13th Congress of the International Society of Soil Science Vol. 5, Hamburg, Germany: 492-504.

Suri M., Cebecauer T., Hofierka J., Fulajtar E., 2002 - Erosion Assessment of Slovakia at regional scale using GIS. *Ecology*, 21: 404-422.

Wischmeier W.H., 1959 - A rainfall erosion index for a universal soil loss equation. *Soil Sci. Soc. Amer. Proc.*, 32: 246-249.

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

Yu B. & Rosewell C.J., 1996 - A robust estimator of the R-factor for the universal soil loss equation. *Transactions of the ASAE*, 39 (2): 559-561.