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An Estimated Erosion Map for the Aterno-Pescara River Basin

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Abstract: In order to design and test an efficient coastal management procedure it is necessary to know at least approximately the mass of eroded soil and the solid transport quantity in the basin of the rivers that "feed" the coast. In this paper we have used the USLE model to obtain a first guess of the erosion in the Aterno-Pescara catchment, which was chosen as representative of the Mediterranean basin typology. However, the USLE model, as any other empirical model, needs to be fine tuned to a location before its results can be trusted. In view of this, our study also suggests the deployment of a gauging network in the catchment based on that first guess.

Keywords: coastal management, soil erosion, Pescara basin, USLE model, gauging network

1. INTRODUCTION

Soil is one of the most important natural resources and, due to its physical, biological and chemical functions, it has a major environmental role. Its structure and fabric are modified by various natural processes, among which soil erosion is the foremost. Human activities are generally responsible for accelerating this process, until the potential productivity of soil and its fertility are significantly reduced.

Soil erosion is responsible for the continuous modification of the shape and elevation of the natural ground surface. In fact, due to the erosive actions associated with rain, wind, frost and melting snow, soil particles are detached from either outcropping rock deposits or from soil like deposits. Then, the particles removed from the parent formations are transported to lower elevations. Hence, the characteristics of a natural or geological erosive process are governed by the climatic characteristics of the area and also by the resistance of the parent formation.

In dry and hot climatic conditions, the parent rock formations are exposed to intense solar radiations. These cause a significant increase in temperature with subsequent dilation of the material, until fracturing occurs. Thereafter the exposed top of the rock breaks into fragments; these are transported by wind or by rare rainy events until they also break into smaller elements that eventually reduce to sand grains.

On the other hand, under humid and wet climatic conditions, the erosive process is controlled by the chemical and mechanical actions induced by water. Water passing through the atmosphere is enriched with carbon dioxide; when it reaches the ground it can enhance the weathering process of various rock materials. Essentially, the hydrological cycle is in fact responsible for isolating the soil particles and causing their movements, that is, for the erosive process (Baganello and Ferro, 2006).

The effect of precipitated water will depend on the characteristics of the precipitation (duration and intensity), on the physical and hydraulic properties of the soil along the ground surface and below it, on its water content at the beginning of the rain, on the current agricultural processes and on the amount and characteristics of the vegetation.

Human activities may produce a significant loss of soil making soil erosion effects associated to natural events worse.

In this paper, we will construct an approximate erosion map for the Aterno-Pescara basin, selected as representative of the Mediterranean typology. Our ultimate purpose is to test an integrated coastal management aiming at a more effective coastal preservation. To fulfill it, we will need an assessment, by means of models, of both the eroded mass and the solid transport in and along the river basin.

The erosion map tells us both the typology and the quantity (as percentage) of surface affected by soil erosion, linking this knowledge to the slope, rainfall data, lithology and land use of the area. We will use a quantitative, empirical model of rill and inter-rill parcel erosion, the USLE model. It is one of the most widely utilized technique available for estimating soil erosion.

The use of this equation makes possible a comparison of the results obtained with other transnational studies. The added value of this work is thus due to the possibility to use different applications in different contexts or the same methodologies in different areas.

The rest of the paper is arranged as follows: in the first section we will describe the Aterno-Pescara river basin. In section two we shall describe the USLE model. Finally, in section three we will show and discuss the results we have obtained.

2. CHARACTERISTICS OF THE ATERNO-PESCARA RIVER

The Aterno-Pescara is a river situated in the region of Abruzzo, in central Italy, on the eastern cost (Figure 1). It drains a basin which covers approximately 3171 km^2, 75% of which lies in L'Aquila province, 23.5% in Pescara province and 1.5% in Chieti province. The Aterno-Pescara River flows for about 145 km from its source, in the Civitella Mountain (1603 m a.s.l.), to its outlet, in the Adriatic Sea at Pescara, and its mean altitude is 925 m a.s.l. (Figure 2).

Figure 1. Location of the Aterno-Pescara River Basin.

Aterno River receives the waters of Sagittario River near the village of Popoli, and then it becomes the Pescara River. The only natural lake of a certain importance in the region, the Scanno Lake, is located in the Sagittario river valley, at an altitude of 922 meters. Downstream of the Scanno Lake, the S. Domenico dam intercepts the Sagittario river, whose sediment load is practically nil, having been filtered by the natural barrage of the lake. On both Sagittario and its left tributary, the Gizio river, there are diversion structures for irrigation of the Sulmona plain. Downhill the Aterno-Sagittario junction, the Pescara River is joined by the Tirino River, on which some diversion structures were built for irrigation and hydropower generation, including the Capodacqua dam which has a storage capacity of 1.6 Mm^3. Immediately downstream the Aterno-Pescara river is intercepted by the Alanno-Pescara hydroelectric system, which consists of four intake structures and four hydropower plants (Farroni, A. 2001). Figure 3 shows the position of the main dams in Aterno-Pescara basin.

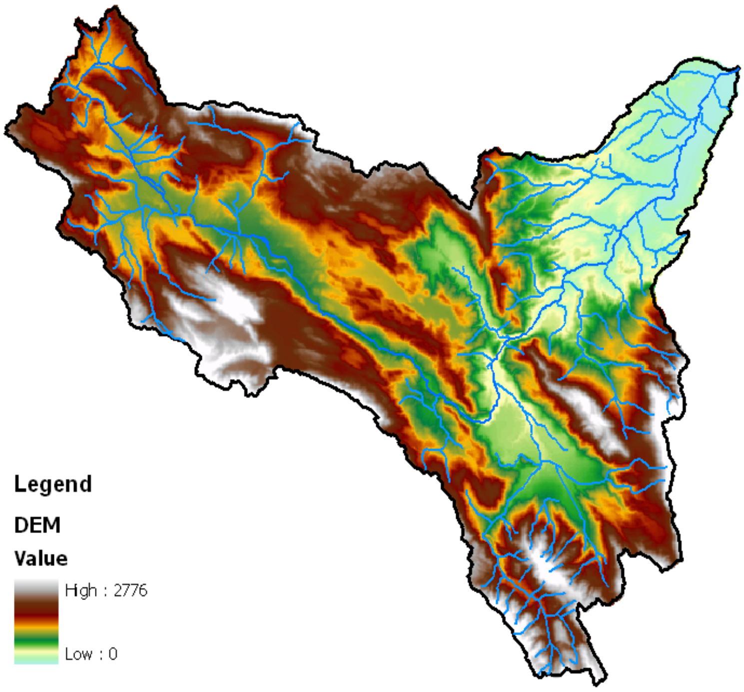

Figure 2. Digital Elevation Model of Aterno-Pescara basin.

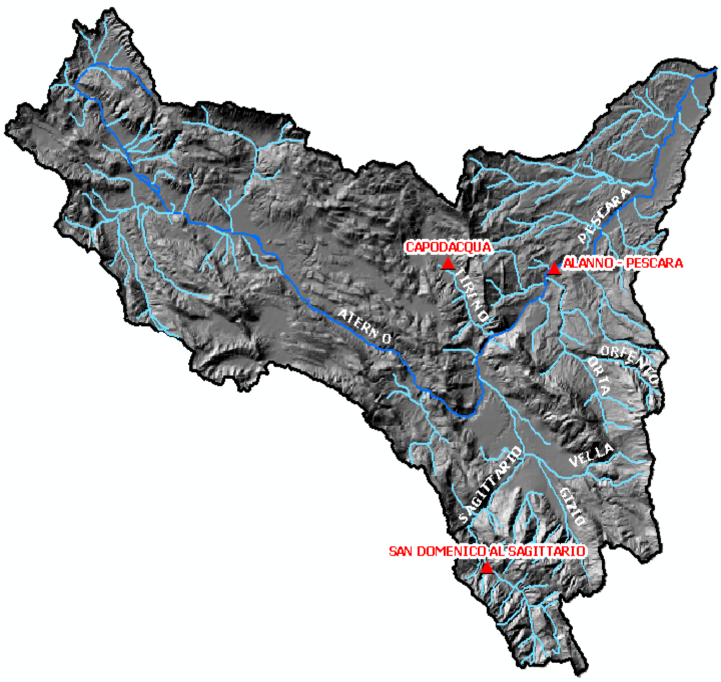

Figure 3. Dams in Aterno-Pescara river basin.

The principal hydrometric stations located on Aterno-Pescara river are shown in Table 1 which also contains their main characteristics.

Table 1. Hydrometric stations located on Aterno-Pescara.

Reach	Station	Catchment Area (km^2)	Permeability (% of total area)	N. of observation years	Qmin (m^3/s)	Qmean (m^3/s)	Qmax (m^3/s)
Aterno	Molina	1303	60	58	0.08	5.23	143.00
Sagittario	Villalago	108	89	42	0.25	1.34	6.80
	Capo Canale	599	93	59	0.72	6.85	58.00
Tirino	Madonnina	322	98	24	3.65	7.91	23.39
Pescara	Maraone	2003	70	59	9.10	26.84	122.00
	Santa Teresa	3125	58	57	18.40	51.76	1096.67

Various hydraulic structures capable of trapping significant amounts of eroded material carried by minor streams are situated along the Aterno-Pescara basin. Data on suspended sediment transport are those recorded by turbidity gauging stations and collected by the Italian National Hydrographic Service (Office of Pescara). In particular, the available data for the Pescara river are referred to the Santa Teresa station and cover the period between 1951 and 1971. This means that there are no recent published data.

For the Pescara river, the average suspended sediment flow rate is *40.6 kg/s* and the specific suspended sediment flow rate is $0.8\ kg/m^3$ (the data are taken from the "Annali Idrologici" edited by the Italian National Hydrographic Service – Office of Pescara).

The lithologies of the Pescara basin, beside alluvial deposits, mainly consist of calcareous and dolomites in the upper part of catchment, of marls and calcareous marls in the central part and of clays in the part of basin nearer to the coast line (Figure 4).

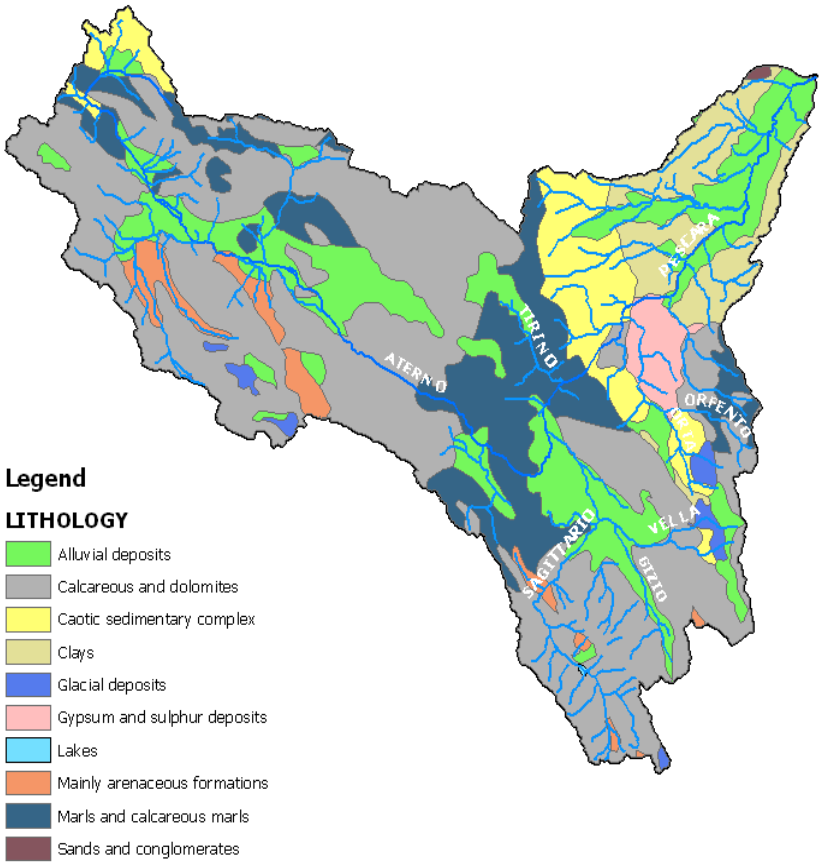

Figure 4. Aterno-Pescara Lithology map.

3. THE USLE MODEL

Erosion models can be broadly classified according to several characteristics. The first distinction between models is whether they are:

1. Qualitative – based on the direct observation of the erosion process in a given area, and the subjective assessment of its possible extension to neighboring areas;
2. Semi-quantitative – factors influencing erosion are weighted according to their (supposed) influence in the process, and the result is usually the attribution of an erosion class;
3. Quantitative – the same factors are explicitly parameterized and combined together to give a quantitative estimate (or forecast) of the actual erosion.

We will concentrate on quantitative models. Among these, a further distinction is usually drawn between so-called empirical models and physical models. The former are statistical in nature and are really only valid for the regions and soil types where they have been calibrated. On the contrary, the latter deduce the equations describing erosion from first principles, such as the physical equations of mass and energy conservation, and are more mathematically rigorous and universally general. They are also considerably more complex than empirical models.

However, it is perhaps worthy to note that empirical models are still based on physics – because they model the same physical process, *i.e.* erosion. On the other hand, physically based models are still based on empirical laws: Namely, the empirical laws of physics.

With respect to the spatial representation of the parameters, models can be *lumped*, that is, they neglect the spatial variation of the variables, or *distributed*. Furthermore, they can consider a continuous time scale, or restrict themselves to each single erosive event.

The Universal Soil Loss Equation (USLE – Wischmeier and Smith, 1978) is a quantitative, empirical model of rill and interrill parcel erosion with lumped parameters and continuous time scale. Developed uninterruptedly since 1954 at the National Runoff and Soil Loss Data Center of the Perdue University (*e.g.*, RUSLE – Revised USLE – Renard *et al.*, 1997), it is based on extensive erosion data from studies throughout the USA (more than 10000 plot-years of data from 50 locations in 24 states).

USLE is designed to predict the long term average soil loss in runoff from a field area under a specific cropping and management system. Indeed, it was initially developed for use in agricultural contexts.

The soil loss at a given site is given by the product of six major factors:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P, \qquad (1)$$

where:

- A [$ton \cdot ha^{-1} \cdot year^{-1}$] is the average annual soil loss;
- R [$MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot year^{-1}$] is the climatic factor, or rainfall aggressivity index;
- K [$ton \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$] is the soil erodibility factor;
- L and S are topographic factors (respectively slope length and slope steepness factor);
- C is the crop/vegetation cover and management factor;
- P is the conservation or support practice factor.

In Figure 5 we show in flowchart form how the USLE works, from its input data to the final result, that is, the erosion map for the considered area.

The R factor represents the rainfall and runoff erosivity index for a given location. For each erosive rain event (events with precipitation height less than 12.7 *mm* are not considered erosive) it is given by $R = E \cdot I_{30}$, where E is the total kinetic energy as a function of the rain intensity and I_{30} is the maximum 30-minutes intensity. Finally R can be obtained by summing over all the events for a given year.

However, the need of very specific data often makes the calculation of R according to its definition impossible, and simplified methods must be devised. These are based either on the total annual precipitation P or on the Fournier Index F (Arnoldus, 1980), which is given by $F = \sum_{j=1}^{12} \frac{p_j^2}{P}$, where p_j is the monthly precipitation for month j. P or F are then linked to R according to empirical formulas.

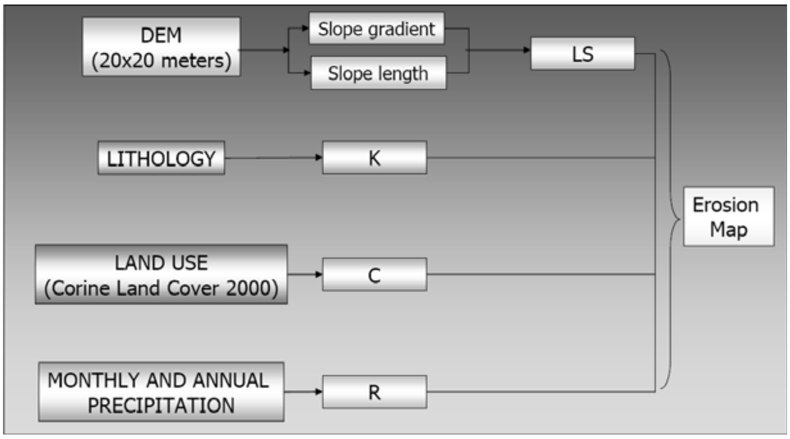

Figure 5. USLE flowchart.

Some studies (*e.g.* Ferro *et al.*, 1999) suggest that P and F be linearly correlated, thus making the added complications in the computation of F not necessary.

Different authors have proposed different ways to retrieve R from P or F. Each method is optimized for a certain location, and there is, as usual, no guarantee that it will work if applied elsewhere. To circuit this problem, we have used several relationships and have averaged the resulting rainfall erosivity indexes. Table 2 shows these equations and the reference where they can be found.

Table 2. Approximate R equations

Arnoldus – linear (1980)	$R = (4.17 \cdot F - 152)/17.02$
Arnoldus – exponential (1977)	$R = 0.302 \cdot F^{1.93}$
Yu & Rosewell (1996)	$R = 3.82 \cdot F^{1.41}$
Renard & Freimun – F (1994)	$R = 0.739 \cdot F^{1.847}$
Renard & Freimun – P (1994)	$R = 0.0483 \cdot P^{1.61}$
Lo et al., (1985)	$R = 38.46 + 3.48 \cdot P$

We have used Italian Agency for Environmental Protection and Technical Services (APAT) data from the twelve rain gages (Figure 6) of the Abruzzo region which are necessary to close the Thiessen polygons, and have obtained R averaged over ten years (1991-2000).

The soil erodibility factor K is a quantitative description of the inherent erodibility of a particular soil. It measures soil particles susceptibility to detachment and transport by rainfall and runoff with respect to a reference parcel.

The reference parcel, or standard condition, is an erosion plot 72.6 *ft* (22.13 *m*) long on a 9% slope, maintained continuously fallow, tilled up and down hill periodically to control weeds and break crusts that form on its surface.

Some of the factors that enter into the calculation of K are (Wischmeier *et al.*, 1971):

- Texture (*i.e.* the size of the soil particles);
- Structure (*i.e.* how the soil particles fit together);
- Organic matter;
- Permeability.

As with the rainfall erosivity index, several authors have developed different, and sometimes simplified, ways to compute *K*. We have used the lithological characteristics to assign *K* values, according to Table 3.

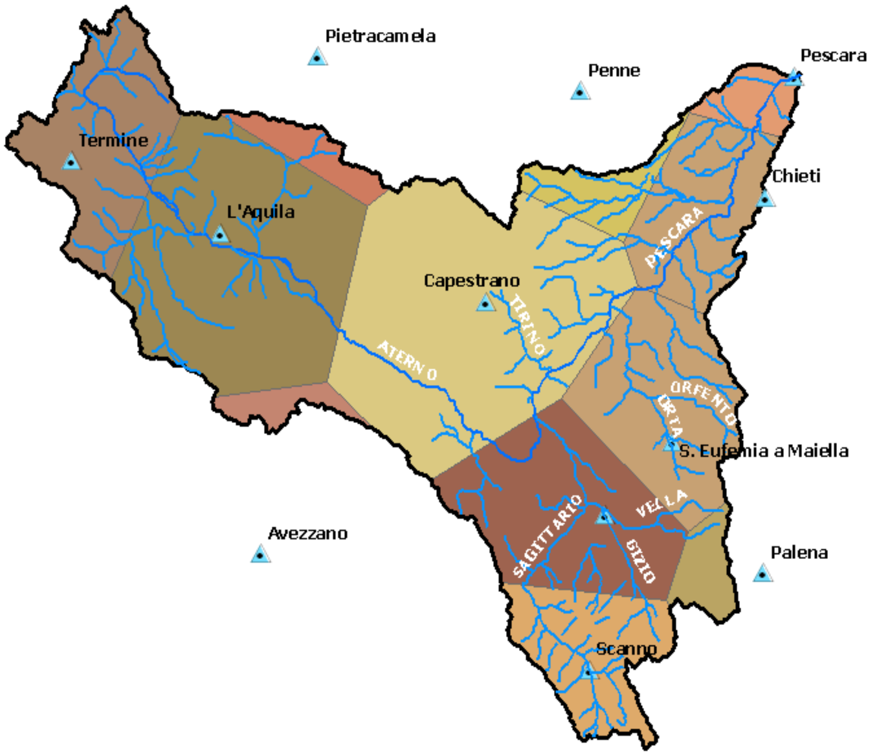

Figure 6. Rain gages spatial distribution and Thiessen polygons

Table 3. Soil lithology and corresponding erodibility factor.

LITHOLOGY	K
Alluvial deposits	*0.029*
Clays	*0.025*
Calcareous and dolomites	*0.013*
Chaotic sedimentary complex	*0.031*
Glacial deposits	*0*
Gypsum and sulfur deposits	*0.010*
Mainly arenaceous formations	*0.020*
Lakes	*0*
Marls and calcareous marls	*0.020*
Sands and conglomerates	*0.052*

The crop/vegetation cover and management factor reflects the effect of cropping and management practices on erosion rates. It is the factor most often used to compare the relative impacts of management options on conservation plans.

In particular, *C* parameterizes the shielding effect of vegetation, as the rainfall erosivity will be more severe where there is no vegetation to absorb and dissipate the kinetic energy of precipitation. Thus, it depends explicitly on the *R* factor of each precipitation event, as well as on the soil crop and/or vegetation cover during *that* event. Its exact calculation would then require both the instantaneous precipitation and an accurate record of the culture and vegetation rotation.

In our simplified framework, then, as we have done for both *R* and *K*, an alternative way of computing *C* must be found. Namely, we have used the CORINE Land Cover 2000 (CLC2000) database. Values of *C* have been attributed to all the occurring land use types according to the values cited in literature (see Table 4).

Table 4. CORINE land use and corresponding C values.

Land Use Code	Description	C	Land Use Code	Description	C
111	Continuous urban fabric	*0*	**231**	Pastures	*0.02*
112	Discontinuous urban fabric	*0*	**241**	Annual crops associated with permanents crops	*0.12*
121	Industrial or commercial units	*0*	**242**	Complex cultivation patterns	*0.12*
122	Road and rail networks and associated land	*0*	**243**	Land principally occupied by agriculture with significant areas of natural vegetation	*0.12*
123	Port areas	*0*	**311**	Broad-leaved forest	*0.004*
124	Airports	*0*	**312**	Coniferous forest	*0.004*
131	Mineral extraction sites	*0*	**313**	Mixed forest	*0.004*
133	Construction sites	*0*	**321**	Natural grassland	*0.05*
141	Green urban areas	*0.005*	**322**	Moors and heathland	*0.05*
142	Sport and leisure facilities	*0.005*	**324**	Transitional woodland scrubs	*0.007*
211	Non-irrigated arable land	*0.4*	**331**	Beaches, dunes, sand plains	*0.3*
221	Vineyards	*0.1*	**332**	Bare rock	*1*
223	Olive groves	*0.1*	**333**	Sparsely vegetated areas	*0.3*

Let us now look at the *L* and *S* factors. *L* is the slope length factor, representing the effect of slope length on erosion. It is the ratio of soil loss from the field slope length to that from a *22.13*-meters length on the same soil type and gradient. Slope length is defined as the distance from the origin of overland flow along its flow path to the location where deposition begins or where runoff flows into a defined channel.

S is the slope steepness factor. It represents the effect of slope steepness on erosion. It is the ratio of soil loss from the field gradient to that from a 9% slope under otherwise identical conditions.

L factor and *S* factor are usually considered together and defined as the topographic length-slope factor (hereinafter *LS* factor) which is a function of both the slope and length of the land. The longer the slope length, the greater the amount of cumulative runoff. Also the steeper the slope of the land, the higher the velocities of the runoff which contribute to erosion.

To incorporate the impact of flow convergence, the hillslope length factor was replaced by upslope contributing area *A* (Moore and Burch 1996, Mitasova et al. 1995, 1996, Desmet and Govers 1996). In modelling erosion in GIS, it is common to calculate the LS combination using a formula such as:

$$LS = \left(\frac{FA \cdot CS}{22.13}\right)^{0.4} \cdot \left[\sin\left(\frac{s}{0.0896}\right)\right]^{1.3} \tag{2}$$

where the slope length is estimated from the *Flow Accumulation* (*FA*), which is the number of cells contributing to flow into a given cell. *CS* is the cell size and *s* is the slope steepness of the cells being used in the grid based representation of the landscape. *LS* can be estimated from the Digital Elevation Model (DEM).

The technique suggested by Engel (1999) is used to determine *LS* factor. Since RUSLE is only suitable for estimating erosion due to interrill and rill processes, it's necessary to enforce an upper bound on the slope length. It was assumed an upper bound of 160 meters for slope length. This means, for our DEM of 20 meters cell size, a maximum value for flow accumulation of approximately 8 grid cells. Flow accumulation grid is obtained using the tools of Arc-Hydro extension within the ArcGIS/ArcMap environment. Both slope gradient and slope length are calculated using the tools of the Spatial Analyst extension: from the toolbar of Spatial Analyst/SurfaceAnalysis/Slope; Spatial Analyst/Raster Calculator.

The expression (2) is then implemented in *Raster Calculator* as follows:

Pow([flowacc] * 20 / 22.13, 0.4) * Pow((Sin([slope] * 3.14 / 180) / 0.0896), 1.3) (3)

where *flowacc* and *slope* are the theme names used for flow accumulation and slope steepness grid files.

4. RESULTS AND DISCUSSION

Rain erosivity, soil erodibility and slope can be considered as naturally occurring factors that determine the sheet and rill erosion processes. The conservation or support practice factor (*P* factor) is assumed to be 1 in this study (as we are interested in estimating theoretical erosion when no best practices are followed). Hence, the result we obtain by multiplying the erosivity factor (*R*), soil erodibility factor (*K*), crop factor (*C*) and topography factor (*LS*) using Raster Calculator is the catchment potential erosion, which is shown in map form in Figure 7. The five ordinal classes of quantitative output of predicted soil are defined in Table 5.

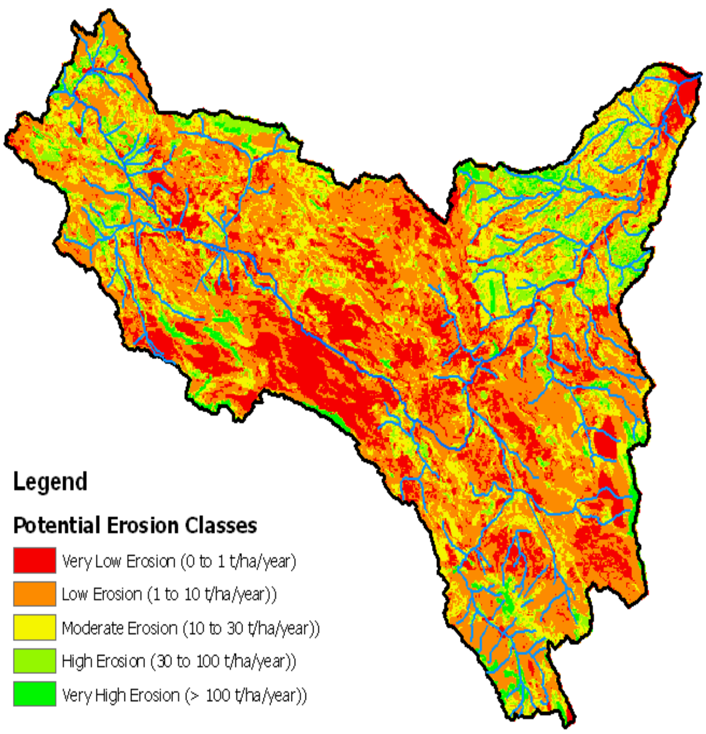

Figure 7. Potential Erosion Map of the Aterno-Pescara basin.

Table 5. Derivation of the ordinal categories of soil erosion potential.

Erosion Class	Numeric Range (t/ha/year)	Erosion Potential
1	0-1	Very Low
2	1-10	Low
3	10-30	Moderate
4	30-100	High
5	> 100	Very High

Table 6 shows the area of the different potential erosion classes in the catchment. As can be seen from the table, nearly 3.5% land of the catchment has very high erosion potential, and nearly 8.7%

land of the catchment has high erosion potential. These areas should be treated as the erosion hazards and watershed management practices should be adopted there to prevent the erosion.

For each major land uses we calculated the area percentage of different potential erosion classes. We found that the surfaces more affected by soil erosion are the non-irrigated arable lands (Corine Land Cover Code = 211), which represent 39.26% of areas characterized by an average annual soil loss A>30 t/ha/year (4th and 5th erosion classes). Area of non-irrigated arable lands is about 15% of the total basin area. About 19% of the non-irrigated arable lands is included in the 4th erosion class, and about 13% in the 5th erosion class.

Table 6. Area of different erosion classes in the basin.

Erosion Class	Area (km^2)	Area (%)
1	1580	49.8
2	801	25.3
3	405	12.8
4	275	8.7
5	110	3.5

Unfortunately there are objective difficulties in developing an actual appraisal of the erosion processes in the studied basin: empirical data are scarce and unstructured and an understanding of the spatial and temporal dynamics of natural environmental processes remains highly uncertain.

However, we can use our study to provide, besides a first order approximation of the real erosion, a guide to where actually increase the density of the observations in order to fit the model to the physical characteristics of the Pescara basin. We could then create a monitoring network capable to obtain sufficient data for describing the spatial and time variability of soil erosion and sediment load transportation. This network could consist of gauging stations established in significant sites, and in particular, in significant cross sections of the basin stream network.

To identify these sites we must consider both the erosion map, the presence of inline structures (dams, weirs or intake structures) and the contributions of the single sub-catchments.

Possible gauging stations and their positions in the river basin are shown in Figure 8. In particular, we placed a first gauge in the upper part of the river basin (Treponti Station on Aterno River); a second one (Molina Station on Aterno River) before the major river junctions to identify the initial sediment contribution of the upstream sub-basin, and a third one before the downstream valley reach (Maraone Station on Pescara River). Moreover at least one gauge should be placed at each main tributary outlet to determine the tributaries' sediment supply. We should especially consider those tributaries related to the two dams of Capodacqua (Madonnina Station on Tirino River) and San Domenico (Capocanale Station on Sagittario River) or characterized by a basin with high slope gradients (Bolognano Station on Orta River). A last gauge needs to be located at the mouth of the Pescara River (Santa Teresa Station) where suspended sediment transport measures were collected in the past (see section 2, namely Table 1).

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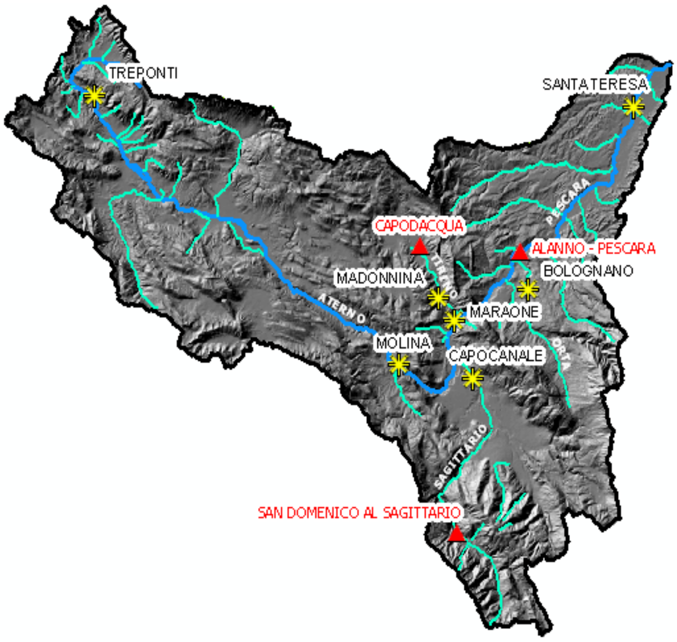

Figure 8. Spatial distribution of gauging stations for sediment load determination in Pescara river basin. The stations are represented by stars, whereas the red triangles show the position of the dams (compare with Figure 3).

REFERENCES

Arnoldus, H.M.J. (1977). Methodology used to determine the maximum potential average soil loss due to sheet and rill erosion in Morocco Assessing Soil Degradation. FAO Soils Bulletin, 34, 8–9.

Arnoldus, H.M.J. (1980). An approximation of the rainfall factor in the Universal Soil Loss Equation. Assessment of Erosion, De Boodt M. and D. Gabriels eds., Wiley, Chichester, UK.

Bagarello, V. and Ferro, V. (2006): Erosione e Conservazione del Suolo. McGraw-Hill.

Engel, B. (1999). Estimating Soil Erosion Using RUSLE (Revised Universal Soil Loss Equation) Using ArcView. http://danpatch.ecn.purdue.edu/~engelb/abe526/gisrusle/gisrusle.html.

Farroni, A., Magaldi, D. and Tallini, M. (2001). Total sediment transport by rivers of Abruzzo (Central Italy): prediction with the RAIZAL model. Bull Eng Geol, 127, 61-121.

Ferro, V., P. Porto and B. Yu (1999). A comparative study of rainfall erosivity estimation for southern Italy and southeastern Australia. Journal of Hydrological Sciences, 44(1), 3-24.

Lo, A., El-Swaify, S.A., Dangler E.W. and Shinshiro, L. (1985). Effectiveness of EI30 as an erosivity index in Hawaii. In: Soil erosion and conservation, S. A. El- Swaify, W. C. Moldenhauer and A. Lo (Eds.) Soil Conservation Society of America, Ankeny, 384–392.

Mitasova, H., J. Hofierka, M. Zlocha, L.R. Iverson, Modeling topographic potential for erosion and deposition using GIS. Int. Journal of Geographical Information Science, 10(5), 629-641. (reply to a comment to this paper appears in 1997 in Int. Journal of Geographical Information Science, Vol. 11, No. 6), (1996).

Moore I.D. and Burch, G. (1986b). Modeling erosion and deposition: topographic effects. Trans of ASAE 29(6):1624-1630, 1640.

Moore, I.D. and Burch, G. (1986a). Physical Basis of the Length-Slope Factor in the Universal Soil Loss Equation. Soil Sci. Soc. Amer. J. 50:1294-1298.

Renard K. G. and Freimund J. R. (1994) Using monthly precipitation data to estimate the R-factor in the revised USLE. J. Hydrol., 157, 287–306.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder (1997). Predicting Soil Erosion by Water – A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Dept. of Agric., Agric. Handbook, n. 703.

Wischmeier, W.H., and D.D. Smith (1978). Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. U.S. Dept. of Agric., Agric. Handbook, n. 537.

Wischmeier, W.H., C.B. Johnson and B.V. Cross (1971). Soil erodibility nomograph for farmland and construction sites. Journal of Soil and Water Conservation, 26, 189-193.

Yu, B. and Rosewell, C.J. (1996). A robust estimator of the R-factor for the Universal Soil Loss Equation. Trans. ASAE, 2, 559–561.