IMPLEMENTATION OF A G.I.S. BASED GEOENVIRONMENTAL ANALYSIS METHOD AIMED AT RESERVOIR PROTECTION

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Abstract

This study is part of research. which is being developed by the authors. aimed at:

a) forecasting and indirect evaluation of reservoir sedimentation. in the absence of measured data;
b) pinpointing of the areas. flowing into a reservoir. where the risk of erosion is higher. with a view to concentrating protection intervention on these zones;

these are particularly relevant subjects in reservoir planning and management.
The authors have already proposed a geoenvironmental analysis method to assess the risk of erosion using a G.I.S. framework. by employing the G.I.S. ARC/INFO® [2,3]. This method uses G.I.S. technology to carry out the geomorphic quantitative analysis of the test area. so as to apply the statistical relationships existing between the geomorphic parameters of concern and the sediment yield of water streams. The quantitative evaluation of erosion and its variability in the area studied has been carried out using this method.
This paper is aimed at further developing these methodological proposals. applied to the Torrente Camastra watershed (Southern Apennines. Italy). This is in order to compare the erosion evaluation. indirectly obtained. to data about the sedimentation in the "Ponte delle Fontanelle" reservoir. existing in the Torrente Camastra [4].
The compared results will be assessed. interpreted and discussed in this paper in order to verify the method proposed.

This research concerns the forecasting and indirect evaluation of areas and extent of erosion in the watersheds of reservoirs. The aim is to forecast reservoir sedimentation. in the absence of measured data. and to pinpoint the areas at highest risk to erosion in the watersheds. so as to apply land-treatment measures[1] specifically to these zones.
The area studied (Fig. 1) is the watershed which flows into the "Ponte delle Fontanelle" reservoir on the Torrente Camastra (Southern Apennines. Italy).
The authors have applied the erosion evaluation method [3] developed through G.I.S.[2] ARC/INFO® technology.
Following this method, the basic geographic themes (streams and divides) taken from available maps (in Italy I.G.M.I. topographic maps to a scale of 1/25000 are suitable for this purpose). aerial photographs and ground surveys have been fed into the G.I.S..
The computer procedures developed have performed the *automated geomorphic quantitative analysis* [2] of the test area. resulting in a number of geomorphic parameters georeferenced in the G.I.S. framework.
The geomorphic parameters obtained have been introduced into a number of statistical equations concerning the sediment yield of water streams [3]. In particular these refer to the suspended load since this represents the main constituent of the stream load in major temperate zone water streams

[1] Such measures have been shown to be the most effective form of protection against soil erosion.
[2] Geographic Information System.

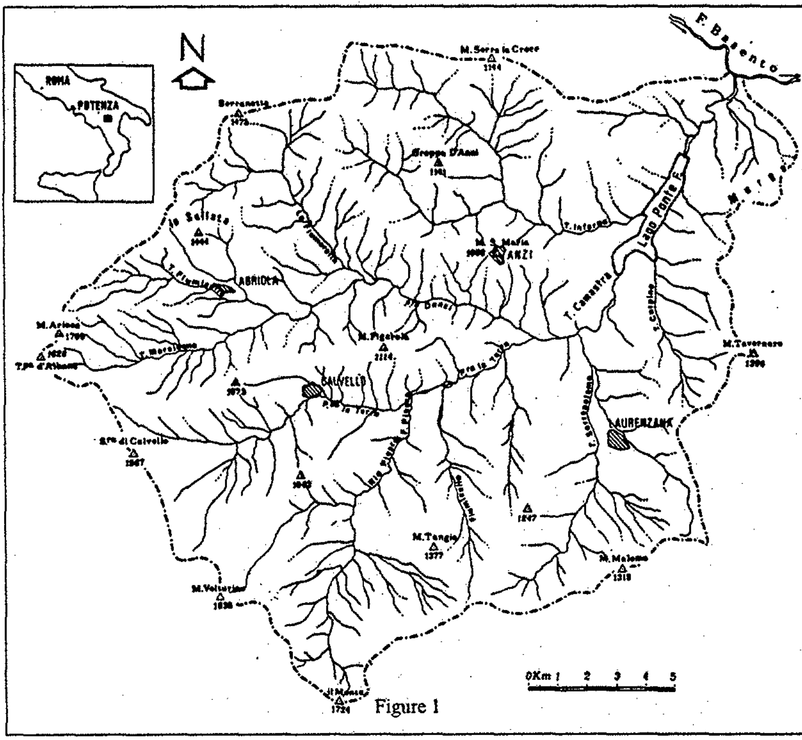

Figure 1

whose basins are predominantly emplaced on sedimentary terrigenous fine-grained lythotypes, as in the case under study. Therefore we approximated the suspended sediment yield of the main water course as being equal to the rate of erosion in its watershed.

The equation used to forecast the *mean annual suspended sediment yield* **Tu** (the mass of solid material which on average crosses a section of reference in one year per surface unit of basin), expressed in ton/km^2/yr, is the following:

$$\log \mathbf{Tu} = 1.447803 + 0.326190\,\mathbf{D} + 0.102467\,\mathbf{\Delta a} \qquad (1)$$

in which the independent variables are drainage density $\mathbf{D}$[3] [6], in km/km^2, and hierarchical anomaly index $\mathbf{\Delta a}$[4] [1], dimensionless.

This equation was chosen from those available [3] because *it presents the maximum* value of the correlation coefficient r^2, as equal to 0.962806.

[3] Average length of streams within the basin per unit of area.

[4] Ratio between the value of the hierarchical anomaly (the smallest number of 1st order streams necessary to make a drainage network perfectly conservative) and the number of 1st order channels actually present in the drainage network.

The values of the quoted geomorphic parameters for the basin contained by the "Ponte delle Fontanelle" dam are: **D**=3.51 km/km^2, **Δa**=1.15, then the estimated value of **Tu** is 406 ton/km^2/yr.
To evaluate the erosion variation, affecting the area studied (342.6 km^2), the T. Camastra basin was divided into 1st level subbasins [2]. The method of erosion evaluation [3] was applied to each of these subbasins. Table 1 shows the calculated values of the geomorphic parameters and of **Tu**.

Subbasins	Area (km^2)	**D** (km/km^2)	**Δa**	**Tu** (ton/km^2/yr)
Torrente Inferno	55.48	2.68	1.34	288
Fiumara di Anzi	92.78	3.95	0.83	663
Fiumara la Terra	115.34	3.89	0.88	641
Torrente Serrapotamo	39.01	4.32	0.94	898
Torrente Carpino	15.47	3.52	1.20	524

Table 1

As shown, the area of the 1st level subbasins vary from roughly 15 to over 100 km^2. therefore it was decided to further subdivide these subbasins into 117 2nd level subbasins and to apply the **Tu** evaluation method to these.
Higher values of drainage density were not compared in the statistical sample analysed [3], therefore the **Tu** values calculated using equation (1) are. in this case, too high, at times even unrealistical so.
As a result, when **D** > 6 km/km^2,

$$\log \mathbf{Tu} = 1.296671 + 2.602049 \log \mathbf{D} + 0.004722\ \mathrm{ga} \quad (2)$$

was applied, since applying the logarithm decreased the influence of higher values of drainage density.
In this equation, where r^2 is equal to 0.942733. hierarchical anomaly density ga[5] [1], expressed in km^{-2}, is taken into consideration.
The results are summarised in an erosion map (Fig. 2), in which the basin contained by the "Ponte delle Fontanelle" dam has been subdivided and classified according to the extent of sediment-production rate into:
not evaluable **Tu** = areas drained directly by the T. Camastra and its main tributaries, to which the method is not applicable:
very low **Tu** = 2nd level subbasins with a resulting **Tu** < 500 ton/km^2/yr
low **Tu** = 2nd level subbasins with a resulting 500 < **Tu** ≤ 1000 ton/km^2/yr
medium **Tu** = 2nd level subbasins with a resulting 1000 < **Tu** ≤ 2000 ton/km^2/yr
high **Tu** = 2nd level subbasins with a resulting 2000 < **Tu** ≤ 3000 ton/km^2/yr
very high **Tu** = 2nd level subbasins with a resulting **Tu** > 3000 ton/km^2/yr
Figure 2 demonstrates that much of the basin is characterised by a low or very low contribution to the T. Camastra sediment yield, while only small sections of the area show high erosion rates. This is in direct correlation to the relatively low value of **Tu** obtained when taking the entire basin into consideration (406 ton/km^2/yr).
The T. Camastra Tu value obtained can be compared with data [4] on the sediment thickness which accumulated in the reservoir over a twenty-year period from the date of damming (1971-1991). The data indicate a sediment volume equal to $1.14 \cdot 10^6$ m^3 and therefore a sedimentation rate of 57000 m^3/yr.
By applying the Lane and Kölzer method [8], modified by Miller [10], and the Lara and Pemberton method [9] to several of the samples taken from the reservoir deposits, we obtained an average specific weight [11] equal to 910.5 kg/m^3. The *mean annual contribution to sedimentation in the*

[5] Ratio between the value of the hierarchical anomaly (see note [4]) and the basin area.

approximately evaluating A=10-20% **E**:
therefore:

$$\mathbf{E} = \mathbf{D} + \mathbf{T} + \mathbf{A} \tag{3}$$

By expressing *trap efficiency* **Te** of the reservoir [5], as being equal to $\frac{\mathbf{D}}{\mathbf{D}+\mathbf{T}}$, equation (3) can be rearranged as

$$\mathbf{E} - \mathbf{D} = \mathbf{A} + \mathbf{T} = \mathbf{A} + \mathbf{D} \cdot \left(\frac{1}{\mathbf{Te}} - 1\right) \tag{4}$$

The evaluated T. Camastra **Tu** clearly corresponds to **E** in (3) on the basis of the previous statement, while S, calculated from sediment mass in the reservoir after twenty years use, corresponds to **D** in the same equation.
To verify the application of the method proposed, the reservoir **Te** should be evaluated: this depends both on various natural conditions (climatic, hydrographic, hydraulic factors; sediment yield characteristics) and on anthropic causes (primarily linked to the management of the dam) [11].
By applying equation (4) the **Te** of the reservoir studied is low, roughly 40-45%; however this value seems fully justified on the basis of both the basin's natural factors and the management of the dam. In fact it is known that at least until 1991 the runoff from the first autumnal rainfall[7] (the study area being classified as a "Cfsb" Köppen and Geiger climatic type [7]), was immediately discharged.

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[7] This runoff is characterised by a very high sediment yield, also due to outcropping rocks.

reservoir per unit of area of watershed S is equal to roughly 151 ton/km^2/yr; this value is slightly more than 1/3 of the **Tu** value calculated using the above mentioned method [3].

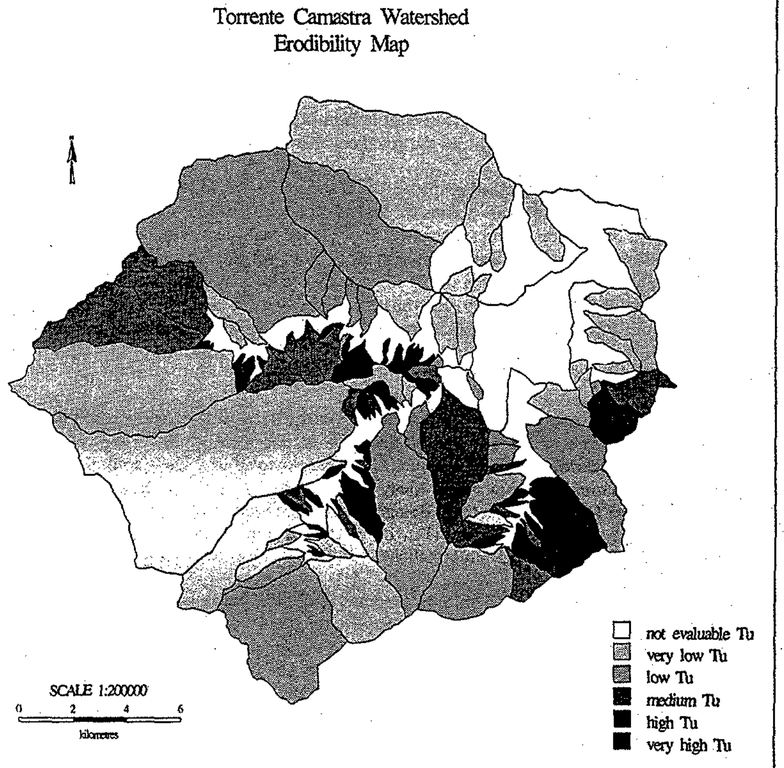

Figure 2

By defining:

E: detrital material eroded by surface water upstream from the dam;

D: permanent deposits on the reservoir bottom after twenty years use;

T: detrital material discharged from the reservoir together with water;

A: detrital material eroded, transported and deposited by water courses upstream from the reservoir[6]

[6] This process is also due to the individuation of a new local base level of erosion (reservoir water level) until a new quasi-equilibrium state is reached.