

## ***Interactive comment on “A spatially distributed analysis of erosion susceptibility and sediment yield in a river basin by means of geomorphic parameters and regression relationships” by S. Grauso et al.***

**S. Grauso et al.**

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First of all, we are very grateful to the three Anonymous Referees and to Dr. Paolo D’Odorico for their reviews. Their comments are a valuable contribution in order to improve our manuscript. We also would like to say that we appreciated the opportunity given by this open discussion, which was constructive and to the point.

Overall, the Referees were quite critical. The main reasons of criticism, accordingly to our opinion, can be synthetically summarised in the following issues:

1) The objective of the study is not clear. It is also not clear which benefits can be

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gained from this approach.

- 2) No convincing proof was provided of the validity of the regression equations for the Calvano watershed. The confidence in the method is not justified.
- 3) The regression equations are not physically-based and no convincing explanation is provided that they could account for the erosion process for “the right reason”.
- 4) The uncertainty in the observed data and sediment bulk density was not taken into account.
- 5) The validity of the approach for different scales is not substantiated enough.
- 6) The link high sediment yield-high sediment deposition and therefore high risk of flooding is never established in the manuscript.

The Referees raised many other objections but in our opinion the major issues are those mentioned above. We would deal with all the major and minor Referees' if we are allowed to revise the paper. We will explain in detail in our rebuttal document how each of the comments was addressed. Within this first short reply, we would like to concentrate our attention on the six relevant issues identified above, in order to substantiate our confidence in the validity of the proposed approach.

## 1. Objective of the study and value of the approach

The assessment of sediment yield is an important issue in engineering practice. With our study we have tried to provide a suitable-for-purpose working approach that may allow one to gain a technically and scientifically relevant insight into the order of magnitude of the sediment yield, in order to be able to design river engineering works.

In the introduction, we explained the need to provide a suitable diagnostic tool that may be useful in real applications when extensive data are lacking. The study-area we considered is an example of the Italian hilly territory comprised between the Central

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Appennine ridge and the Adriatic Sea. Here the hydrogeological risk is managed by the local Administrations with protection actions which have to be designed by preliminarily evaluating the potential sediment yield. To this aim, we chose to adopt and test a statistical model, which, in its conceptual form, has been largely adopted worldwide at different scales, from the global (i.e. the Fournier's world map of erosion) to the national and local scale (many citations could be made to this aim and will be included in the revised paper).

The empirical nature of this approach is not different with respect to that of other models and methodologies, like the USLE equation or many other empirical relationships used for the evaluation of sediment yield and bed load transport. These approaches are widely applied in practice, sometimes in very variegated contexts, for the same reasons that motivated our study.

In our analysis we applied an already existing model, namely, the multiple regression equations proposed by Ciccacci et al. (1987), who studied the relationships between sediment yield and geomorphic-climatic parameters in 20 watersheds of central-southern Italy. This model can be considered, to date, the only approach holding a large scale validity, at least for what concerns continental Italy.

A more clear description of our objectives could be provided in the introduction. We will add more citations to substantiate the practical validity of the approach. Moreover, additional references can be provided regarding the procedures and algorithms used to derive internal basin subdivisions basing on DEM. We also can make clear how the DEM was derived from single elevation points and contour lines.

## 2. Validity of the regression equations for the Calvano watershed

The Calvano catchment is located inside the wide geographical region covered by the catchments selected by Ciccacci et al. (1987). One of them is the Tavo river catchment, which is very close to the Calvano catchments and therefore is characterised by

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very similar geological and climatic conditions. In addition, other authors (Ceci et al., 1998) have utilised the same approach in the Tavo catchment itself, in comparison with other assessment models, by means of a former regression equation by Ciccacci et al. (1980), and obtained a very good result as the predicted sediment yield was almost according with reservoir sedimentation data (difference less than 10

Our extrapolation of the results is fully justified from a physical point of view and it is supported both by field observations and by the conclusions of the local Authority technical commission (AA.VV., 1999).

There is another important point in favour of the reliability of the proposed regression equations, a point that we did not mention in the first version of the paper. In fact, plot observations (Grauso, 1994) have been carried out on badlands located in proximity of one of the partial tributaries basins of the Calvano catchment. The soil loss direct measurements resulted to be in good agreement with the sediment yield estimated by the regression equations. These latter outperformed other soil erosion models considered as term of comparison, like CREAMS and WEPP (physically based) and the USLE equation (empirical). We are willing to provide extensive details about this comparison in the revised manuscript, as requested by the Referees, to strengthen the results of our study.

We are also willing to provide additional proofs of the validity of the regression approach. We are willing to carry out a cross evaluation by using the data by Ciccacci et al. (1987). We will re-calibrate the regression equations by excluding each of the 20 basins in turn, therefore applying each time the regression approach on the excluded catchment in validation mode. This exercise will provide a convincing proof of the performances of the method in out-of-sample applications, therefore providing a useful indication for the validity in the study site. Moreover, we are willing to carry out an evaluation of the uncertainty associated to the observed data. See our reply in Section 4.

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### 3. Physical basis of the regression equations

We believe the method we applied has a strong physical justification. One of the two variables considered in the regressions is the drainage density, which is a well known parameter. For this reason we have omitted extensive details, while for the index of hierarchic anomaly we have provided a clear explanation.

The meaning and significance of the two variables are clearly explained. They describe, respectively, the dissection degree of a catchment, namely, the network density, and its topology. That is, its degree of organisation in a hierarchical tree-shaped structure. For this reason, the highest are the drainage density and the hierarchic anomaly, the highest is the erosion potential and related sediment yield. This is typically what is occurring in badlands catchments (with their morphological and lithological implications) or on southfacing catchments, where the vegetal coverage is poorer than on the northfacing ones, given the lower soil humidity, and then sediment erosion processes and channels network development are favoured (Castiglioni, 1933; Passerini, 1937; Panicucci, 1972; Lulli Ronchetti, 1973; Dramis et al., 1982; Nisio, Prestininzi, Scarascia Mugnozza, 1997).

For general information we also referred in the first version of the paper to studies that revealed how in some areas, like in Sicily (that is, in a peculiar geographic setting distinct from continental Italy), drainage density is less significantly correlated with sediment yield than elsewhere. Therefore, in such circumstances, other explanatory variables are to be identified. Probably we did not clarify enough in the paper that this is a potential suggestion for future research, about how to improve the reliability of the approach when one refers to different geographical contexts.

### 4. Uncertainty assessment

We agree with the Referees that we did not carry out an evaluation of data uncertainty in the first version of the paper. First of all, we would like to make clear that the data are

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of course uncertain, as they were derived through point measurements of the reservoir geometry or assessment of the sediment volume removed after dredging. However, we wish to emphasise that any hydrological measurement is affected by uncertainty and we wanted to be clear in admitting the limits of our data.

We feel that it is now necessary to stress that these data constitute a good piece of information. We did not exhaustively describe in detail how the data were estimated for the sake of manuscript brevity. We would like to stress that we do not think the level of uncertainty is as such to make the data unreliable for validation purposes, as they depict a situation which is consistent with direct measurements operated in similar catchments (Ciccacci et al., 1980; 1987).

However, we recognise that the evaluation of data uncertainty is an important issue and therefore we are willing to quantify the data uncertainty in the revised version of the paper by also analysing how it affects the evaluation of model performances. To this end, we propose to carry out a GLUE-like study by assuming a feasible range of variation for the observed data and the drainage density. This would allow us to obtain a probability distribution of model performances, under suitable assumptions, therefore permitting to carry out a statistical evaluation of the reliability of the method.

We also would like to make clear how the bulk density value for reservoirs sediments was evaluated. In absence of direct measurements, a theoretical average value (1.2 g cm<sup>-3</sup>) attributable to soft fine to medium-coarse sediments (non consolidated) was adopted. This value is supported by geotechnical reports and investigations on reservoirs located in different parts of Italy. For example: - investigations on the Penne reservoir, located on the Tavo river, provided humid bulk densities ranging from 1.6 to 1.9 g cm<sup>-3</sup> (Ceci et al., 1998). This value should be converted into dry bulk density before comparing sedimentation data with predicted sediment yield. Without direct measurements, we can only argue that dry bulk densities less than 1.6 can be expected. - Dry bulk densities ranging from 0.891 to 1.455 were measured on sediment samples from a reservoir located in Sicily (Grauso Onori, 2006). -

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Van Rompaey et al. (2005), in their modelling analysis of sediment yield in Italian catchments, utilised sedimentation data from 40 reservoirs, located from north to south of the Italian peninsula, by considering a mean bulk density of  $0.865 \text{ g cm}^{-3}$  which was derived from the direct analysis of sediments in only 4 reservoirs of the entire dataset. We have adopted a unique value of bulk density with reference to the very small reservoirs located close each other, within the Calvano catchment (È). Within the uncertainty analysis we could consider different density values ranging from a minimum (less consolidated sediment) to a maximum (more consolidated sediment), that is, from  $1.2$  to  $1.7 \text{ g cm}^{-3}$ .

## 5. Validity of the approach for different scales

The application of the regression equation at different sections of the main drainage basin helps us to highlight the different sediment yield potential from contributing catchments. It is generally acquired that the total sediment amount from eroded slopes do not reach the basin outlet. This is verified at different scales and it is valid both for tributary and principal catchments depending on the relative “sediment delivery ratio” which is an inherent characteristic of a given catchment. With this statement, it is not surprising if the sediment yield potential from the badlands portion of the Calvano catchment can account for almost the totality of the overall sediment yield. This evidence was also verified in field, by observing huge sediment deposition and overflowing in correspondence of the badlands catchments outlets on the main stream, where a strong slope change occurs. These confluences represent the critical points where interventions by land managers and stakeholders should be addressed. And this is the task of an assessment methodology which should be suitable to be utilised in real applications.

Probably, we did not state clearly enough our objectives, which are not to validate the empirical relationships nor to understand the physical processes in the Calvano watershed, but to demonstrate how the empirical relationships can help to describe and to quantitatively assess, at least in the order of magnitude, the sediment supplies

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at different sections of the watershed.

## 5. Link between high sediment yield and high sediment deposition

The link between high sediment yield and high sediment deposition is established at p. 632 I. 5-10 (description of the study-area). This is not our conclusion but the starting point and the justification for our study. The link of cause-effect between the sediment yield from tributaries and minor channels and its deposition at the confluence with the main stream was highlighted by the already cited local Authority technical commission (1999) and by the Italian Vulnerable Areas AVI project report financed by the National Research Council (CNR, 1993). We are willing to provide more details about this issue.

We feel we can successfully address all the other comments provided by the Referees, that in our opinion refer to minor problems. We recognise that the first version of our paper was not detailed enough in clarifying some crucial aspects of our analysis. We feel that a major revision could allow us to partially rework the analysis and the paper and therefore to address the major and minor concerns of the Referees.

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