Responses to the comments of Dr Lorenzo MARCHI on egusphere-2022-1494

Editorial template

Each comments of the reviewer are presented in the normal font.

> *The responses of the authors are indented and written in italic.*

General comment

This study focuses on the assessment of coarse sediment volumes in mountain catchments, which is an important issue for the control of sediment-related hazards and risks. The development of statistical models that relate sediment volumes to catchment characteristics is not novel, but this work shows some valuable features, namely the frequency analysis of time series of sediment volume data, the inclusion of sediment connectivity among the predictive factors, and a careful evaluation of model performances. The analysis is based on a very good dataset and is performed using up-to-date statistical techniques.
I am reporting below some comments hoping that they could be useful in the paper's revision.

> *We thank very much Dr Marchi for this feedback. We feel lucky to benefit for his comments and long experience on this topic.*

Table 1.

The equations (b) and (c) of Rickenmmann (1997) define envelope curves (EC).

> *Thanks, we were not sure. This will be added.*

The equations involving catchment area, slope and the geological index, proposed by D'Agostino et al. (1996) and D'Agostino and Marchi (2001) could be removed because they have a similar structure to the equation by Marchi and D'Agostino (2004), which is based on a larger dataset.

> *Thanks for this information. The equations of 1996 will be removed. We however would like to keep the mention to the paper of 2004 to recall the simple envelope curve V = 70 000 A to echo with the paper of 2019 mentioned below. Also the idea to add the return period into the envelop curve of the last equation taken from D'Agostino and Marchi 2001 deserves being mentioned.*
> *We will add the remark that the sample of 2001 was part of the one of 2004 on the line describing the latter.*

The authors could consider the equations proposed by Marchi et al. (2019) that link debris-flow volume (V_{DF}) to catchment area (A_B) for various quantiles. These equations, which are based on a sample of 809 debris-flow volumes in the Eastern Italian Alps (https://doi.pangaea.de/10.1594/PANGAEA.896595), are not intended as predictive tools, while they aim at defining the scaling relationships between these variables. We observe, however, that the equation for the 99 percentile ($V_{DF}=77000\pm7000\cdot A^{(1.01\pm0.06)}$) is similar to the empirical envelope line (fitted by eye) proposed for the same region by D'Agostino and Marchi (2001).

Very good point: we will add the reference and the equation in Table 1 and will add as a remark in the introduction (L36):

> *"Interesting trends can nonetheless be capture on small samples: the envelope curve* $V = 70,000 \cdot A$ *that was eye-fitted by D'Agostino and Marchi (2001) on 84 events is for instance very close from the quantile equation* $V_{99\%} = 77,000 \cdot A^{1.01}$ *proposed by Marchi et al. (2019) for the same region on a ten time larger dataset."*

Type of flow process

The records of sediment transport events include information on the type of flow process, i.e. debris flow of flood (line 84). It is likely - and some details about that would be welcome - that some catchments were affected by only one type of sediment transport process, whereas other catchments experienced both floods with intense bedload and debris flows. It seems to me that the information on the type of sediment transport has not been fully exploited, and events with different transport mechanisms have been processed together to derive the equations for predicting sediment volumes. Developing separate equations for floods and debris flows could have permitted to gain significant insights into the capability of different processes in delivering sediment in the catchments of the studied region. I understand, however, that the smaller sample size for separate processes could have been detrimental to the robustness of the analysis.

The issue of the type of sediment transport processes also arises in section 2.3.3 with the application of two approaches based on catchment topography to the recognition of the dominant sediment transport. Little is said about the agreement between the transport process predicted according to Wilford et al. (2004) and the transport process documented from debris basin dredging and RTM archives (section 2.1).

This is also a key point. Dr Marchi is absolutely correct, our sample is composed of a mixture of bedload-prone and debris flow-prone basins, as well as basins experimenting mixed regimes with routine events being often bedload and extreme events sometimes being debris flows. This is a very complicated question.

Actually, the RTM database mentioned L84 is sadly not systematically clear about the process type and often does not cover small events that nonetheless resulted in a dredging of the basin (an event is recorded only if it triggered some damage). This point will be clarified in the revised version:

> *"Briefly, this database provides information on past events that triggered damages in the catchments (to protection structures, roads or buildings), giving details of any causes, eventually information on the process type (i.e. debris flow or flood) and sometime also the volumes of sediment transported."*

Most dredging data being for not extreme events, we consequently have too often poor knowledge or unclear evidences of the process type of the event. In several catchments, we do not even know the main dominant process. This would require interviews of the catchment managers of the one hundred basins and careful cross control by field visit. This is out sadly of the scope of this work. Therefore, we did not exploited this information *mostly because it is missing (and we agree that it would be of great interest).*

Another elements: when the processes are clearly identified as simple bedload or clear debris flows, it indeed usually make sense to analyse them separately: the unit volume of the latter being generally much higher. To our experience it becomes more complicated when debris floods events are found and more generally for catchments where several, mixed processes occur and change along the propagation. We will provide the following complementary information at the end of §2.3.3 (near L.148):

> *"For these reasons, we adopted the method of Wilford et al. (2004) for the study. Only this automatic classification was used without exhaustive cross-checking with field evidences due to the lack of availability of relevant and rigorous documentation on this question. In addition, many catchments experience mixed regimes where frequent and small events are rather related to bedload transport while infrequent, larger events might be debris flows (e.g. Theule et al., 2012; Marchi and Cavalli, 2007; Hübl, 2018): assigning a category is thus challenging. We decided to use the simple classification proposed by Wilford et al. (2004) – which is straightforward to use even on a undocumented catchment – simply to test if these classes emerged as sub-samples having clearly different sediment production capacities. It must be acknowledge that this is only a simplistic indicator and not a field-based evidence of a flow process type."*

Finaly: the whole sample is only of about a hundred catchment, i.e. not very large. Thus, as pointed by Dr Marchi in his comment, splitting it in two or three subsamples whose boundaries would have somewhat been arbitrary due to a lack of information would have very probably decrease the statistical rigour of the analysis. This point was missing and deserved to be addressed as pointed by Dr March. We thus added to the discussion on the input parameters (§4.1) a paragraph on this idea:

> *"The classification of the dominant process type according to Wilford et al. (2004) also does not appear as a meaningful variable in our analysis. This could appear surprising because typical event magnitude of debris flows are usually quite higher than of bedload events for a given catchment size (Rudolf-Miklau and Suda, 2013; Hübl, 2018). Rather than relying on a simplistic classification as we did here due to a lack of information, in further research it could be of interest to classify more precisely the type of process involved in each catchment, and, if possible, for each events based on field and historical evidences (D'Agostino, 2013; Kaitna and Hübl, 2012). Then it would be possible to fit extreme values predictions that would be process-specific in addition to be catchment-specific. Extending the dataset to other sites and eventual regions would be necessary not to perform such analyses on excessively small sub-samples."*

I presume that the three classes of sediment transport processes considered in Figure 5 are based on the application of the approach by Wilford et al. (2004) (i.e., not on archive data): this could be clearly stated in the caption. I suggest describing the three classes in Figure 5 using a legend within the figure instead of the caption.

> *A legend will be added to the figure and its title will state that indeed, the classes are taken from Wilford et al. 2004. See below. Thanks for the suggestion.*

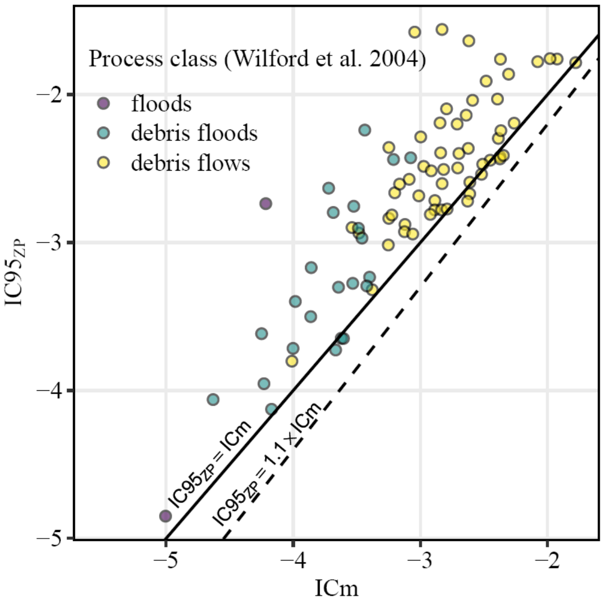

Figure 5. Relationship between IC95$_{ZP}$ and ICm of every catchments illustrating that the equation IC95$_{ZP}$ = 1.1 · ICm is a reasonable lower envelope curve.

Sediment contributing areas

Does the recognition of “bare soil” permits discriminating bare soil from bare (outcropping) rocks? Both bare soil and bare rocks, if connected to the channel network, supply sediment for debris flows and fluvial transport. However, the erosion rate is usually much higher on bare soil/debris than on outcropping rock.

> *Indeed, this is a shortcut that we miss to mention. We pooled all surfaces of connected bare soil and rock in the sediment contributing area. The difference in lithology and associated variable erosion rate was supposed to be analysed in the Geological Index (but did not prove statistically meaningful). We will add in the section describing the sediment contributing area:*
>
> > *“It is worth mentioning that bare bedrock is also included in the sediment contributing area in our approach. Although bedrock also produce sediment, bare soil has usually a higher to much higher erosion rate. Any surface area of connected bare soil or rock is however considered equally in our approach, their lithological*

> > *differences is assessed in the Geological Index presented in the next sub-section."*

Regarding the use of channel area as a proxy of sediment source area (lines 165-166, 207), it could be of some interest to remember that the area of main stream channel was found to be significantly correlated to the sedimentation of reservoirs in one of the earliest studies that applied multiple regression to sediment yield estimation (Anderson, 1949).

> *Thank you very much for this reference that we did not know. It will be added.*

Roughness in sediment connectivity

The rather coarse DTM resolution could hamper the computation of the topographic roughness as an index of impedance to sediment transfer across the landscape. The optimal DTM resolution in the computation of the topographic roughness depends on the spatial scale of the geomorphic processes investigated. This issue is discussed in Crema et al. (2020) and a conversation on GitHub: https://github.com/HydrogeomorphologyTools/Connectivity-Index-ArcGIS-toolbox/issues/4
However, in the wide frame of this study, which computes the index of connectivity IC to derive an independent variable lumped at the catchment scale, this detail on the computation of the topographic roughness can be considered less critical than for studies aimed at representing sediment connectivity in a distributed way.

> *Very relevant remark: indeed, it is because we extracted with the same approach and normalization method the IC on our dataset, and, most of all, because we extracted just a lumped value that we allow ourselves to use such a coarse DTM. We will add the following remark:*
>
> > *"In addition, the coarse DTM resolution was likely less critical because this study does not address an in-depth analysis of the IC distribution within the catchments but rather seek to extract a lumped variable at the catchment scale."*

Discussion

The authors frankly acknowledge the limits in the accuracy of the developed equations, which "capture a relevant first approximation but cannot be very precise" (line 290). The suitability of statistical equations for sediment volumes prediction has received different opinions in the literature. In the case of debris flows, Rickenmann (1999) found that some predictive equations "may overestimate the actual debris-flow volume by up to a factor of 100" and recommended "to make a geomorphologic assessment of the sediment potential rather than using these equations". This statement could sound too drastic, especially if the equations are based, like in this study, on careful data collection and thorough statistical analysis.
However, in my opinion, the geomorphological assessment of mobilizable debris remains the core of any estimation of sediment volumes in torrent catchments, while the statistical equations relating sediment volumes to catchment parameters provide at most a useful comparison with the geomorphological estimates. I don't know if the authors agree with my point of view: I am proposing it as a hint for extending the discussion on the application of the predictive models developed in this study, including the integration with other methods, now briefly mentioned in lines 370-371.

We fully agree with Dr Marchi on this point. The end of the discussion was indeed too short. We will add to the end of the discussion a few more details:

> *"Such empirical equations are obviously only one type of tool between many others. Debris-flow and debris flood hazard assessments require further in situ and historical analyses adapted to the stage of study (Jakob, 2021). When possible, the practice in France (also consistent with Jakob et al., 2022), is to compare the results of empirical equations with: (i) in-depth historical analysis (Marchi and Cavalli, 2007; D'Agostino, 2013). Such analyses sometimes enable to gather sufficient information to perform a local extreme value fit as in this work, most of the time they only give an order of magnitude of one or a few extreme events. (ii) Simple computations can be done using rainfall data associated with hypothesis on runoff coefficient and on solid concentration of the flows (e.g. Marchi and D'Agostino, 2004; Rickenmann and Koschni, 2010). (iii) Field visits finally help to map potential debris sources in term of length of active gullies or erodible bed and associated possible erosion rate in m3/m of channel (e.g. Hungr et al., 1984; Marchi and D'Agostino, 2004). The latter exercise is key to ensure that there is indeed available material to form debris flows and debris floods and helps correcting other empirical approaches, for instance in catchments with extended bare rock area of strong igneous rock that are often supply limited."*

References

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We thank again very much Dr Marchi for his time spent in helping us to improve our work!