Anonymous Referee #2
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Point 1:
The paper by Morera et al. sets out on a valiant attempt to disentangle the complex relationships between various factors known to influence erosion rates and catchment sediment yield (such as rainfall dynamics, slope steepness, geology and land use) for two large catchment areas in the sub-humid to very dry western Andes of northern Peru, an area known to be subject to major fluctuations in rainfall due to the ENSO phenomenon and for which reasonably long-term streamflow, rainfall and sediment yield data are presented.

Unfortunately, the authors start on a wrong footing by stating that 'there is almost no published data on specific sediment yield for the Central Andes along the Pacific Coast of Peru' (p. 630, lines 22-23) whereas they further claim that 'the relationships between ENSO, precipitation, runoff, and the sediment transport dynamics of the central Andes are poorly understood' (p.631, lines 6-8). Whilst this may have been true at the time their study (which is based on a PhD thesis defended in 2010) was initiated, there are several examples of long-term streamflow and sediment yield studies in relation to the occurrence of ENSO events for the very same region that should/could have been referred to, if only for comparative purposes. A key example of the latter is the thorough analysis of the role of ENSO events in long-term sediment dynamics in the equally large (17 000 km2) Catamoya Chira Basin near the border between Ecuador and Peru by Tote et al. (2011) (Earth Surface Processes and Landforms 36(13): 1776-1788).

In addition, there are reasonably long-term (1987+) streamflow and sedimentation data of high quality (twice daily sampling for suspended sediment) available for the Gallito Ciego Reservoir in northern Peru (draining the 3470 km2 Jequetepeque Basin). Whilst the latter data may not have been published in the regular scientific literature they must be comparatively easy to come by judged by the fact that various international NGOs are using them (a.o. WWF-CARE International). At any rate, both these examples illustrate the overwhelming influence exerted by (strong) ENSO events on annual sediment yield in the area under consideration.

Thus, taking these recent relevant findings into account may help the authors to narrow the scope of their study somewhat and to focus more on disentangling the relative importance of the various factors influencing erosion rates and sediment production, notably ENSO occurrence and such key catchment attributes as lithology and land use (presumably most slopes are steep anyway).

We are pleased that the Reviewer considers that the manuscript "sets out on a valiant attempt to disentangle the complex relationships between various factors known to influence erosion rates and catchment sediment yield (such as rainfall dynamics, slope steepness, geology and land use) for two large catchment areas in the sub-humid to very dry western Andes of northern Peru....".

Actually, recent studies (Lagos et al. 2008, Lavado et al. 2012 and 2013) show that ENSO at the latitudes of the Tablachaca and Santa watersheds show low correlation between ENSO precipitation and runoff. For example see PQ-10 (Santa+Tablachaca watersheds) in Table 4 of Lavado et al (2012). The Mann-Kendall coefficients between hydrological time series and large-scale circulation index (SOI) for Maximum Runoff, Mean Runoff, Minimum Runoff and Rainfall are 0.10, 0.11, 0.18, and 0.19, respectively.

Therefore, exploring the effect of ENSO on sediment production of this watershed does not seem useful, which is why we have deleted Figure 6 from the original manuscript concerning the ENSO. Finally, the ENSO event has a different control on

the precipitation variability in Peru (and consequently on the hydrology and annual sediment yield) depending on the location (latitude).

As we mentioned to Reviewer 1, the revised manuscript focuses on the following points: (i) sediment production differences between watersheds in the western Andes may not be "climatically controlled"; (ii) lithology, combined with slope spatial distribution and mining activities are eligible factors for explaining these differences; and (iii) any study about sediment production in the western Andes cannot be done without a map of possible erosive factors at relevant resolutions.
As mentioned by Reviewer 2, the study by Tote et al. (2011) shows a strong influence of ENSO occurrence on erosion rates and sediment production. But it should be noted that the watershed in that study is located between 2°N and 5°S, while our study deals with watersheds located further south.

Point 2:
The Introductory section of the paper wanders all over the place (including repeated emphasis on chemical aspects that is not followed up later on in the paper) and could be shortened by having such a clearer focus (and line of thought).

We accept the criticism; our statements about these references may have been too direct and needed to be more precise. In the revised manuscript, we have totally rewritten the introduction. We hope this new text is clearer and more convincing.

Point 3:
On a related note, analysis of the paper by Morera et al. is not made any easier by the often convoluted and frequently imprecise style of writing (what to think of the 'Bolivian front size of the Andes' (p. 630, lines 6);
The new revised version of the attached manuscript has been reorganized with a clearer distinction of English terms.

Point 4
Bolivian front size of the Andes' (p. 630, lines 6); **Changed into "Bolivian side of the Andes." (2p, lines 29 in the revised manuscript)**

Point 5
'plate areas' in the river's longitudinal profile **removed in the revised manuscript.**

Point 6
'annual mass balance of water discharge'; **removed in the revised manuscript.**

Point 7
mixing up stream discharge Q and specific SY in the caption of Figure 8 (p. 670) ; **removed in the revised manuscript.**

Point 8
dashed line in Fig. 8; **Changed into solid line (Figure 7 in the revised manuscript.**
dotted line in Fig. 8; **Changed into broken line (Figure 7 in the revised manuscript.**

Point 9
poorly explained summary graphs in Fig. 10; **Detailed in Figure 9 in the revised manuscript.**

Point 10

poorly explained summary graphs in Fig. 11; **Detailed in Figure 10 in the revised manuscript.**

Point 11
Examples of the former include giving ample detail where this is not needed and vice versa: e.g. section 2.2 on lithology which contains a number of incomprehensible sentences even to a trained geologist (as a result, the connection to the subject at hand tends to be lost); or section 2.4 on 'slope degree' which does not give any information on slope steepness in the study watersheds (sic!); or section 2.5 on the climatological context which fails to give any information on the variation in annual or wet-season rainfall with altitude or even for the (undefined) 'second climate zone' as a whole, etc., etc.

We accept this criticism. The revised version of the manuscript has been reorganized with a clearer distinction between data and results (see the revised manuscript attached).

For the geological section, we have clarified the lithologies of both watersheds with standard classifications (Figure 2 and Table 1 have been changed).

Regarding "slope degree" or "slope steepness", both watersheds have the same frequency distribution of slope steepness (expressed in degrees) (see Fig. 8 in the revised manuscript). Note that the frequency shown in the figure has been normalized by the total area of each basin. Because of the similar frequency distributions, we believe that the slope steepness alone could not be the controlling factor for sediment production.

For the climatological description we have added new details to the text (see section 2.5) a new Figure 4. This is described in point 14 below.

Point 12
To this should be added the lack of a clear structure for the paper. Information that belongs in the Introductory or Methods sections (or even Study Area at times) crops up in the Results section (e.g. the classification of ENSO events on p. 640 lines 1-2 and 5-10) and vice versa (e.g. Figure 5 showing historic rainfall, streamflow and sediment concentrations series but placed in the Methods section). More seriously, the Methods section lacks an introductory paragraph detailing how the various types of information are combined in a single robust analysis. Instead, there are scattered (and somewhat vague if not confusing) methodological hints in separate sub-sections (e.g. section 3.1, lines 23-25 on linking slope steepness and lithology; section 3.2, lines 6-11 on linking stream SSY to the lithology map and (lines 11-12) once again, slope distribution per lithology.

See our answer to point 11.

Point 13
Limitations in the basic data are sometimes discussed (e.g. p. 638 lines 26-28 on gaps in streamflow data) but not quantified (i.e. what fraction of the data is missing, etc.) and sometimes not addressed at all (e.g. reference is made to the use of two rainfall stations at 2500-3300 m elevation whilst the discharge gauging stations are located around 500 m, thereby leaving an altitudinal range of as much as 2000–2800 m uncovered in terms of rainfall inputs!

The percentage of missing water discharge data has been specified in the revised manuscript. We understand this comment about the relevance of the rainfall data

presented in the manuscript and agree that a rainfall database with only two stations may have low representativeness given the size of the watershed.
One figure has been added to the revised manuscript to supplement description of the rainfall context (Fig. 4). Based on TRMM rainfall data, this figure show the representativeness of the two rainfall stations for the entire study area (section 2.5 in the revised manuscript).

Point 14
Likewise, contributions by bedload to the overall SSY remain entirely undiscussed although the river beds must be filled with stones of various sizes that are known to be transported during major ENSO events (e.g. blocks of 50 cm diameter crossed the several km Gallito Ciego reservoir in 1997/98 destroying the turbines at the downstream end of the reservoir!).

We agree with the referee that bedload is still an open question in our study as in many studies about sediment yield. Actually, there is no available data about bedload in our dataset. Therefore the annual partition of bedload/suspended load cannot be defined. Following the review about the bedload/suspended load partioning of Turowsky et al. 2010, there is no clear empirical law avalaible to define short or long terms bedload patitioning from watershed characteristics. We don't find also any published work which gives any quantitative estimation of this partionning for andean watershed similar to the Tablachaca and Santa. Thus our estimation of SSY is definitely an underestimation of the real SSY for both watersheds and it is why in the text we always specify that we are working on suspended sediment.

To clarify the relative significance of our results on SSY, we add in the discussion of the new manuscript the following text.

"In this study all measure and analysis is focus on suspended load because of the lack of any data about bedload. Our results on SSY are therefore underestimations of the total sediment yield. Following the review of Turowsky et al. (2010), there is no relevant empirical law to define this partitioning through the characteristics of the watershed. Currently the percentage of bedload varies from 0 to 100 % according to the river context. For andean watersheds similar to the Santa and Tablachaca watersheds, there is no published data about bedload yield. Actually there is bedload transport in the Santa and Tablachaca rivers, looking to the metric size of the bed sediments at many places of the river networks. The bedload estimation is therefore an important task to make the total balance of the sediment yield. Here, all measures, results and discussions are focused on the suspended sediment part; focus, which highlights interesting significant erosion rates and spatial contrasts"

Point 15
Despite these criticisms and despite the absence of clear-cut relationships between specific factors and catchment SSY derived in the study the authors seem to be on the right track when indicating the heavily mined Chimu formation as the most likely culprit of the much higher SSY observed for the Tablachaca catchment given the contrast in relative areas between catchments for this formation. This finding might point the way forward for further useful work in the area. A thorough rewriting of the present paper remains a necessity, however, before these results can find their way into the mainstream hydro-geomorphological literature.

We are pleased that the Reviewer considers that "the authors seem to be on the right track when indicating the heavily mined Chimu formation as the most likely culprit of the much higher SSY observed for the Tablachaca catchment given the contrast in relative areas between catchments for this formation...."

The revised version of the manuscript has been reorganized with a clearer distinction between data and results (see the revised manuscript attached).

References:

Lagos, P., Silva, Y., Nickl, E., Mosquera, K., 2008, El Niño – related precipitation variability in Peru, 14, 231-237

Lavado-Casimiro, W., Felipe, O., Silvestre, E., Bourrel, L., 2013, ENSO impact on the hydrology in Peru, Adv. Geosci., 11, 1-7, doi:10,5194/adgeo-11-1-2013

Lavado-Casimiro, W., Ronchail, J., Labat, D., Espinoza, J.C., Guyot, J.L., 2012, Basin-scale analysis of rainfall and runoff in Peru (1969-2004): Pacific, Titicaca and Amazonas drainages, Hydrological Sciences Journal, doi:10.1080/02626667.2012.672985

Kettner, A., Restrepo, J., and Syvitski, J.. *Spatial Simulation of Fluvial Sediment Fluxes within an Andean Drainage Basin, the Magdalena River, Colombia*. Journal of Geology, vol 118n p. 363-379, DOI : 10.1086/652 659, 2010.

Syvitski, J. P. M., Peckham, S., Hilberman, R., and Mulder, T.: *Predicting the terrestrial flux of sediment to the global ocean: a planetary perspective*, Sediment. Geol., 162, 5–24, doi:10.1016/S0037-0738(03)00232-X, 2003.

Syvitski, J. P. M. and Milliman, J. D.: *Geology, geography, and humans battle for dominance over the delivery of fluvial sediment to the coastal ocean*, Geology, 115, 1–19, doi:10.1086/509246, 2007.30

Syvitski, J. P. M. and Kettner, A.: *Sediment flux and the Anthropocene*, Philos. T. Roy. Soc. A, 369, 957–975, doi:10.1098/rsta.2010.0329, 2011.

Tote, C., Govers, G., Van Kerckhoven, S., Filiberto, I., Verstraeten, G., and Eerens, H.: Effect of ENSO events on sediment production in a large coastal basin in northern Peru, Earth Surf. Process. Landforms, 36, 1776–1788, 10.1002/esp.2200, 2011.

Turowski, J. M., Rickenmann, D., and Dadson, S. J.: The partitioning of the total sediment load of a river into suspended load and bedload: a review of empirical data., Sedimentology, 57, 1126-1146, 10.1111/j.1365-3091.2009.01140.x, 2010.

Walling, DE, *Human impact on land-ocean sediment transfer by the world's rivers*, Geomoprhology, 79, pp 192-216, 2006.