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Interactive Comment

Interactive comment on "Analysis of the drought resilience of Andosols on southern Ecuadorian Andean páramos" *by* V. I niguez et al.

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Thanks for the comments of our article

The answer to the remarks of Wouter Buytaert is started by discussing the general comments.

1. Wouter Buytaert said:

"However, I share the first reviewer's concerns about the use of the term resilience, especially because it is not always clear whether the perspective is the ecosystem itself or the downstream users. The introduction and rationale of the project is very much written from the downstream users' perspective, because of the exceptionally high runoff ratio, and an equally high buffering capacity (i.e. very high base flows and compara-

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tively low peak flows) of the páramo region. As the authors correctly point out, this is indeed related to the extreme soil water retention capacity of the páramo soils. But the obtained results suggest that the ecosystem itself may not be so resilient. The fact that the critical water content of the páramo is found to be exceptionally high suggests that the vegetation may be quite prone to water stress. This is again good from the viewpoint of downstream users, because that means that ET reduces quickly under drought conditions, which reduces soil water depletion and increases the recovery rate. But it may well mean that the páramo itself is quite sensitive to drought, depending on the plants' physiological reaction to water stress (see also the specific comment below). One potentially interesting piece of information that is lacking here is the wilting point, which determines the total available water. Especially since the water retention curve is estimated (11457/4-9), and the wilting point used in the analysis, it would be useful to show the data themselves and discuss them in a bit more detail.

Elaboration of the resilience concept in the above-mentioned context may even be an opportunity for a more thorough discussion on the hydrological behaviour of páramo catchments and how to interpret the response in the context of drought. For instance, another aspect that is worth discussing further is the extremely high wilting point of many páramo soils, including those in the studied region, and what this may mean for the hydrological response and base flows in particular. At least theoretically, water retained beyond wilting point is hydrologically inactive, and therefore not relevant for water resources. Instead of the large water retention of the soils, there is increasing evidence that the páramo catchments' extreme water buffering and streamflow dampening response is rather related to the topography, and the resulting extensive occurrence of wetlands with a high storage capacity, which effectively create extreme variability in the contributing area. All this is very compatible with the findings of the study, but also gives an opportunity for better contextualisation and I would strongly encourage the authors to take this further than the current discussion".

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Firstly, as a part of the answer to the Anonymous referee # 1 we discussed the alternative definitions of “resilience”. In order to avoid possible confusions we propose in a new version of the manuscript to use the term “recovery resilience” (or often also called an "engineering resilience") instead of only “resilience”. Resilience might be misinterpreted as to "ecological resilience", which is a "robustness resilience" and not the definition we used. We also propose as suggested by both reviewers to elaborate more on the definition. Indeed as mentioned by the second referee our hydrological perspective serves in the first place the downstream users. We did not study the ecological resilience, which as dr Buytaert suggested, might not be as good. The new version will avoid this confusion.

Secondly the measured water retention curve or pF-curve as obtained in the soil physics laboratory has been measured. This curve illustrates the well-known high water retention capacity of the Andosols (see the pF-curve, figure 1). The low tension part of the curve (from saturation water content up to the field capacity) shows little change in the soil water content (i.e. the range of negative pressure is: 0-0.33 bar or up to pF 2.3). A large change is observed in the range from 0.33 up to 15 bar, which is in the available water content (AWC). The specific values obtained were: AWC: 0.40 and 0.24 cm3 cm-3, the field capacities 0.835 and 0.531 cm3 cm-3 and the permanent wilting points were equal to 0.43 and 0.30 cm3 cm-3 for Calluancay and Cumbe respectively. In other words, considering just an average depth of the organic soils for the whole area of about 0.50 m, the available water content expressed in millimeters is around 200. For the case in Cumbe (mineral soils), with a similar depth (0.5 m) the AWC is lower and equal to around 120 mm, which is a bit more than the half of the Andosols. The AWC values were used to calculate the volume of water retained by the soils at the catchment scale and the differences in terms of soil water storage will be clearly revealed (figure 1).

Please see the pF-curves in figure 1.

Our soil water measurements and the simulation never reached wilting point. The minimum soil water content values during the drought periods in páramo was not lower than 0.62 cm3 cm-3. Field observations on November 2009, revealed that the plants apparently showed signs of deterioration in the first centimetres but after removal of the top layer (normally composed of dead leaves) the plants did not show a visual deterioration. Nevertheless, the depletion of the soil moisture storage during dry weather conditions clearly lead to stress and had an impact on the transpiration rate. The effect is quantified by the stress coefficient “ks”. In both cases (Calluancay and Cumbe) values no more than 0.50 were calculated. As this vegetation has specific adaptations to high-radiation and cold environment the recovery by the vegetation after drought is good. We also think that tillage, burning and artificial drainage might have a larger and more irreversible impact on the soil water holding capacity of the Andosol as compared to a "natural" drought.

This is in agreement with the remarks of Wouter Buytaert about the plants adaptations: “increase stomatal resistance, reduces the root suction capacity, and in general increases the plants’ sensitivity to soil water potential”.

2. Wouter Buytaert said as a second issue:

“One minor point of the study is the relation between the observations and the modelling. I don’t think that the GLUE analysis provides much added value, and I suggest to take that out. As also pointed out by reviewer 1, neither would I rate the performance of the model as particularly good. There are good reasons why modelling páramo catchments is very challenging, in particular the large spatial gradients of precipitation, which leads to large input errors. This is not a criticism of the model implementation, but warrants a more in-depth discussion of the added value of implementing a model in addition to the more direct analysis of the results”.

Answer:

We are agree with this remark and so the figures and related text in the manuscript about the GLUE analysis will be modified.

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2 Specific comments:

11451/11: "WRB": needs to be written in full (World Reference Base for Soil Resources) and referenced (as is done further down but not here). Also, it is probably good to point out that these are the dominant but not the only classifications. For instance, there are also umbrisols and regosols, among others.

Answer:

The new text will be as follow, “Shallow organic soils -classified according to the World Reference Base for Soil Resources (WRB) (FAO et al., 1998) as Andosols and Histosols are the two main groups of soils that can be found in this Andean region. These groups of soils are the dominant ones, but it is also possible to find Umbrisols and Regosols, among others”.

11452/20: "the first three years have been classified as el Niño years": needs a reference. According to what criterion? If they were, they surely weren’t very pronounced.

Answer:

The new text will be as follow, “Dry periods and droughts in the páramo took place between 2005 and 2012. Accordingly to the monthly Niño-3.4 index published freely by the National Oceanic and Atmospheric Administration (NOAA) (which is used to calculate the Ocean Niño Index -ONI- values), the periods of time for November 2009 up to February 2010 and from August 2010 up to February 2011 were classified as a moderate El Niño(+) and La Niña(-) events respectively (Yu and Kim, 2013; Yu et al., 2011). The maximum sea surface temperature (SST) anomalies registered in the Pacific Ocean (Region 3.4 Average) during those periods of time were +1.42 and -1.46 respectively. A strong El Niño o La Niña events are considered when the SST is between 1.5 and 2 (absolute value, +/-) respectively. More than 2 (+/-) is catalogued as very strong event. Of course the main issue is the lack of rainfall regardless whether it coincides with el Niño or not.

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References:

Yu, J.-Y., Kao, H.-Y., Lee, T. and Kim, S. T.: Subsurface ocean temperature indices for Central-Pacific and Eastern-Pacific types of El Niño and La Niña events, Theoretical and Applied Climatology, 103(3-4), 337–344, doi:10.1007/s00704-010-0307-6, 2011.

Yu, J.-Y. and Kim, S. T.: Identifying the types of major El Niño events since 1870, International Journal of Climatology, 33(8), 2105–2112, doi:10.1002/joc.3575, 2013.

11452/29: "resilience or resistance": concurring with reviewer 1, I find the term resilience a bit problematic here, and would prefer resistance. But it may be worth trying to be more precise as to what kind of soil behaviour would be preferable from a water resources perspective (see above).

Answer:

We have decided to use the phrase “drought recovery resilience” instead of “drought resilience” as well as to analysis the soil behaviour within a water resources perspective. The corresponding text will be modified to be more precise and appropriate (please see also the answer to Reviewer # 1).

11452/23: "the main hydropower projects": which ones?

Answer:

The new text will be as follow, “For instance, the water level in the reservoir of the main hydropower project in the Ecuadorian Andes –The Paute Molino hydropower– reached their lowest values as a consequence of the drought between December 2009 and February 2010. This caused several, intermittent, power cuts in many regions of Ecuador. The power plant’s capacity is 1075 MW. In that period of time the Paute Molino hydropower provided around 60% of Ecuador’s electricity (Southgate and Macke, 1989)”.

Reference:

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Southgate, D. and Macke, R.: The Downstream Benefits of Soil Conservation in Third World Hydroelectric Watersheds, Land Economics, 65(1), 38, doi:10.2307/3146262, 1989.

11452/26: "hydrological capacity": needs a more precise formulation. What capacity?

This relates to my comments above about regulation and buffering.

Answer:

The new text will be as follow, “The hydrological regulation and buffering capacity of the páramo”.

11453/26: "resides on" -> resides in

Answer:

This change has been included in the text.

11454/9: "characterized as" -> "characterized by" or "classified as"

Answer:

“characterized by” has been included in the text.

11454/10: The large difference in catchment area is not ideal, but I understand that it is caused by data scarcity and topographical constraints. It is important to keep the potential consequences in mind when comparing. For instance, may the fact that a higher spatial variability of soil moisture is found for the (small) páramo catchment (11467/15-21) have to do with the fact that Cumbe is much larger, and therefore the hydrological response is longer, which may reduce the sensitivity of parameter b. A dotty plot of parameter b would be useful in that regard. The appendix contains some dotty plots, but apparently not of parameter b.

Answer:

Please see the dotty plots for the parameter “b” in figure 2:

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The figure 2 reveals that of sensitivity of the parameter "b" for Cumbe is larger than for the case of Calluancay. Although the b-parameter for the latter catchment has an optimum, larger values have a lower impact on the NSE. For both catchments the sensitivities are asymmetrical. During the discussions of the results related to the PDM model, and specifically on parameter "b" we had have mentioned that (page 11467, line 18-19) "These results are in line with the literature (Brocca et al., 2012)". The reference cited analysed the spatial and temporal variability of the soil moisture at the catchment scale (Journal of Hydrology). Brocca et al. (2012) summarize the main results as follows: "The two main findings inferred are: (1) the spatial variability of soil moisture increase with the area up to ∼10 km2 and then remains quite constant with an average coefficient of variation equal to ∼0.20; (2) regardless of the areal extension, the soil moisture exhibits temporal stability features and, hence, few measurements can be used to infer areal mean values with a good accuracy (determination coefficient higher than 0.88)."

The Calluancay's area catchment falls inside the first range mentioned by the authors (4.39 km2) and so we found a similar result, a relatively high spatial variability of soil moisture storage reflected by parameter "b". Although, the perspective and approach used by the authors were different –e.g.: a statistical and temporal stability analysis– we are conscious of the potential consequences when comparing different sizes of catchments. For both cases, the hydrological implications are implicit. However, we can extend the discussion in order to reveal in an explicit way the consequences. We are agree in the sense that the differences in the sensitivity of the parameter "b" can be attributed to the fact that Cumbe is much larger, and therefore the hydrological response is longer, which is revealed by the dotty plots of the parameter "b".

11457/1: "soil samples": what type of measurement? Gravimetric?

Answer:

The new text will be as follow, "For Cumbe and Calluancay, the TDR probes were cali-

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brated based on gravimetric measurements of soil moisture content using undisturbed soil samples ($R2 = 0.79$ and 0.80 respectively)."

11457/eq.1: As the time interval is non-infinitesimal, it is better to express the storage variation as $\Delta S/\Delta t$ instead of dS/dt, which is the differential.

Answer:

This change has been included in the new version of the manuscript.

11458/5: "in páramos, the": remove "the"

Answer:

The change has been done in the new version of the manuscript.

11465/4-14: I think that this section can be formulated more sharply. Essentially, what happens is that the xerophytic properties and other adaptations to a high-radiation environment such as the dead leaves increase stomatal resistance, reduces the root suction capacity, and in general increases the plants' sensitivity to soil water potential. The question is of course to which extent this makes the plants more resilient to drought. The low transpiration rate may make them survive longer during drought, but it may also mean that their wilting point is much lower than the typically assumed 15 bar. This generate an interesting trade-off. It is probably not possible to determine with the available data which is the dominant process, I think that this merits some more discussion.

Answer:

This is related to the first remark. So, please see the corresponding answer above.

11467/6-9: the relevance of the robustness of the model as evaluated by the GLUE method is not really clear, and is a bit disconnected from the rest of the paper. I suggest to leave it out to make the paper more focused.

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Answer:

We accept the suggestion of leave out the GLUE method and so the related text and the figure 5 will be updated.

11469/12: "reached values": better "dropped to values" as I assume that these are extreme minima? Also, use "unprecedented values", or "not previously observed" instead of "values never seen before"

Answer:

The new text will be as follow, “During the drought events in 2009 and 2010, the soil water content in páramo dropped to unprecedented values”.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 11449, 2015.

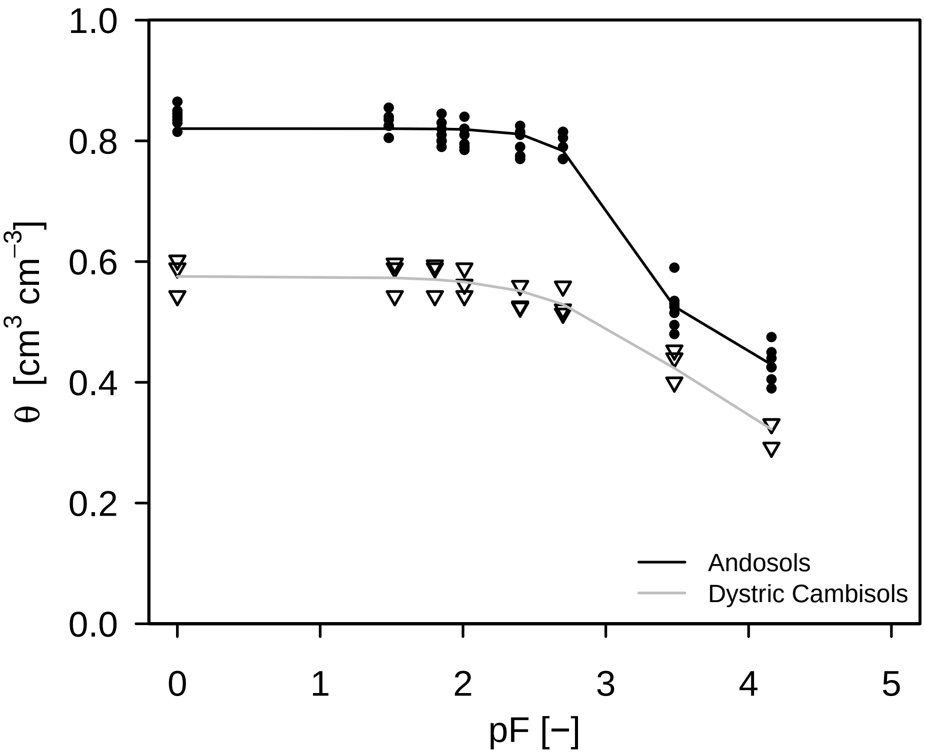

Fig. 1. Modelling of the water retention curve of the Andosols –Calluancay– and Dystric Cambisols –Cumbe– with the Mualem-van Genuchten model

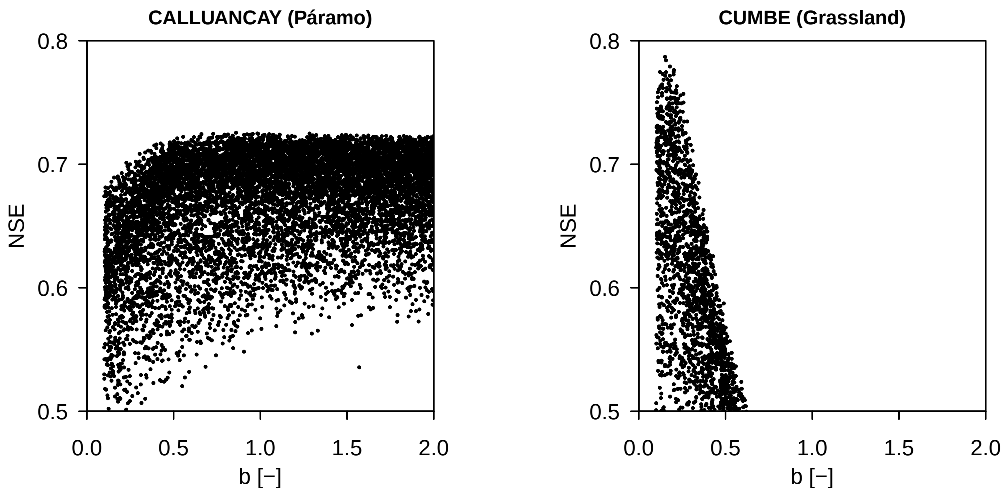

Fig. 2. Dotty plots for parameter “b”, which is the exponent of Pareto distribution controlling spatial variability of soil moisture storage capacity.