

Interactive comment on “Analysis of the drought resilience of Andosols on southern Ecuadorian Andean páramos” by V. Iniguez et al.

V. Iniguez et al.

vicente.iniguez@ucuenca.edu.ec

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Thanks for the comments of our article.

The answer to the comments of the Anonymous Referee # 1 is started by discussing the summary of the interactive comment.

1) The Anonymous reviewer use as title for the general comment: “Is resilience a hydrologically useful concept?” In addition Referee # 1 said: “The authors define resilience as the time needed for the soil to recover to its pre-drought state of water content, once rainfall has started to exceed vegetation demand. I wonder if the authors could just as easily have called this the effective (or maybe maximum?) drought length everywhere in their paper”.

Answer: Resilience is a widely used concept in many areas of natural, human, medical and engineering sciences. This leads to a wide range of definitions and interpretations depending on the scientific domain.

Broadly speaking we can classify the definitions into two groups:

- Robustness definitions: the ability or resistance of the subject under study to withstand a level of disturbance without entering into an unwanted state as compared to the state before the disturbance.

- Recovery definitions: The rapidity of the subject under study to regain initial pre-stressed state after the exposure to a level of disturbance.

The latter definition is also called the "engineering resilience" and requires a more quantitative and system analysis approach. The first definition is most common in medicine and psychology. Both definitions are used in different situations and sciences and have their merits.

In ecosystems research the robustness definition is often preferred. We can cite the review article on ecological resilience by Gunderson (2000); an article with has many citations "In this case [= ecological resilience using the robustness definition], resilience is measured by the magnitude of disturbance that can be absorbed before the system redefines its structure by changing the variables and processes that control behaviour. This has been dubbed ecological resilience in contrast to engineering resilience"

One of the co-authors of our manuscript also co-authored an article on the "assessment of resilience of natural wastewater treatment systems" [Cuppens et al. 2012]. In this article the concept of resilience comparing both definitions is discussed in more detail, but as this was applied in a water treatment context and not in hydrology it was felt that this (self-citation) reference would not be appropriate.

Probably reviewer#1 only accepts the ecological resilience definition which is a robustness resilience. Citing reviewer#1 "Other than that resilience is most often used

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in ecology where it refers to mechanisms by which a population, or a species, or an ecosystem can recover from adverse conditions (or remain relatively stable in terms of its state variables while environmental conditions vary)" points in the direction that he/she objects to the recovery resilience. He/She also starts next paragraph after previous discussion: "Does this make any sense for a catchment?". Later reviewer#1 states "An example for resilience in catchment behaviour could be vegetation regrowth in case of a clearcut.". We must agree that "robustness resilience" (as used in ecological resilience) does not make sense for our manuscript seen from the purely ecological context.

So, our impression is that the reviewer#1 only accepts the "robustness definition" and therefore has strong objections against the use of alternative "recovery resilience". We are of the opinion that both definitions are useful but serve different objectives.

We are not ecologists but hydrologists and therefore not aware about this sensitivity. Although HESS is in the first place a hydrological journal, ecologists do read and publish in this journal. In order to avoid any confusion with the "robustness resilience" as used in defining "ecological resilience" by ecologists, we should in a revised version therefore expand on the definition pointing out the different approaches to resilience. In the title we propose also to use "recovery resilience" in the title in order to avoid confusion with "robustness resilience". Making hydrologists and ecologists more aware about different definitions on resilience would be a bonus to our article.

The major point in our article is indeed the fact that the recovery of the páramo is more rapid as compared to the lower catchment. So in our article the use of "recovery resilience" ("engineering resilience") is fully appropriate and "robustness resilience" (as mainly used in "ecological resilience") would in our case not be appropriate.

Also the length of drought in itself is not the major focus. Rather it is the recovery speed, which of course leads to end of drought. It is also important to point out that the disturbance of the hydrological system consists of periods whereby the evapotranspiration

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exceeds the rainfall. This is also different for both catchments. The rainfall is similar in both catchments but the potential evapotranspiration at his elevation is because of the lower temperature lower. The moment the disturbance ends and the rainfall exceeds again the evapotranspiration the recovery sets in. From a system's point of view the disturbance of the input in the hydrological system occurs when the evapotranspiration demand exceeds the rainfall. The state of the system is characterized by the soil water content. The pre-stressed state is characterized by the soil water content during long periods of non-disturbed input (rainfall exceeds evapotranspiration demand).

As a result, we remain convinced that the use of "recovery resilience" as the time needed for the soil to recover to its pre-drought state of water content after disturbance is fully appropriate and coherent in the context of hydrology. However, thanks to the reviewer#1 we can improve the manuscript by a short discussion on the different concepts of resilience and refine our "engineering or recovery resilience" definition in more detail. Our concern is mainly the water balance and its impact on the water resources.

2) The Anonymous Referee # 1 said as a second issue: "The authors claim that their point measurements are well predicted by the model. I worry that this result is overly optimistic given that scaling moisture contents allows for a constant offset and a constant relative error?" in addition he/she states at the end of the first paragraph: "using a model calibrated and validated on the basis of soil moisture and discharge data".

Answer: The hydrological model used in our paper is the Probabilistic Soil Moisture (PDM) model. This conceptual hydrological model was developed by the Centre for Ecology and Hydrology (formerly Institute of Hydrology, Wallingford). We used the MATLAB version from the Rainfall-Runoff Modelling Toolbox – RRMT, freely available from Imperial College London:

<http://www3.imperial.ac.uk/ewre/research/software/toolkit>

PDM was used with a daily resolution and the input data are precipitation and potential evapotranspiration and it calculates discharge time series. The discharge has been

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used for calibration/validation of the PDM by applying the GLUE methodology. Several references about the PDM model were cited and in one of them is mentioned the site where the official manual of PDM model can be found it for the case of a specific consultation. We considered the PDM model as one of the classical models in hydrology.

The measured soil moisture data is not used as input to the model. However, as most hydrological models the PDM model generates internally state and output variables. These internal derived variables include effective rainfall, actual evapotranspiration, simulated discharge and average distribution characteristic values of the soil moisture storage including the average.

After calibration/validation of the PDM model parameters based on the discharge the simulated PDM average soil water content was compared to the measured soil water content. It should be mentioned that the continuous data-logging of TDR measurements of soil water content is very expensive (far more expensive than operating an automatic weather station and discharge measurement station) and essentially measures (from the catchment point of view) point values. However, one should realize that rainfall and weather-data in most models are equally based on point measurements, so using point measurements for a larger area is not unique.

Anyhow, seen the expense of the soil water monitoring, it is quite logical that observers will select both secure (remember the expense of the equipment) and representative sites. So for both catchments this was done very carefully. In addition certainly the small Calluancay catchment with páramo has a homogeneous soil. But also in the Cumbe catchment a halfway position on a typical slope with typical pasture land use was selected.

We compared the average simulated soil moisture storage (one of the internal state variables from PDM model) with the point measurements of soil water content (6 TDR probes) in our experimental plot (one plot in each catchment). One of the reasons for the selection of the PDM model was because the model take into account -in an

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explicit way- the natural heterogeneous variability of the soil moisture storages within of a catchment. This is done by means of a probability distribution function and hence the name of the model.

The locations in the catchments for the TDR measurements were very carefully selected based on a digital terrain analysis, the soil and land cover maps and good knowledge of the terrain. So we tried to have very representative locations. As consequence, we are convinced that those point measurements of soil moisture content form a good estimation for the real catchment's average soil moisture storage.

As result, the differences or discrepancies between the simulated soil water by a conceptual model and observed soil moisture storage at the point location were relative low. The differences might be due to non-linearities in the reduction of actual evapotranspiration as compared to the potential vegetation demand.

Although one could limit the analysis to the measured soil water data and a simulation of the water balance a small plot and obtain already some interesting conclusions and insights we feel that the comparison to a catchment model is very relevant. Because, the páramo's ecosystem is considered the main water supplier in the Andes, it is important to analyse the response and impacts to extreme weather conditions in the framework of a wider water resources context. The PDM models helps us to understand the consequences for the water supply, which is the primary concern of our research. So, we are not dealing with the ecosystem's view, which is of course also a very important concern.

References:

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