Response to Reviewer # 1

Dear anonymous Reviewer (#1),

Thank you for taking the time to review our manuscript and for your valuable comments! In the following sections, we respond to your helpful suggestions and concerns:

> ***This manuscript describes the evaluation of drought risk in four tropical catchments of Brazil, Colombia, Costa Rica and Cambodia/Vietnam. Drought in tropical areas has been scarcely evaluated; therefore, this paper makes a substantial contribution to the assessment of drought considering hazard and vulnerability to achieve a compound drought risk index. Overall, the manuscript is clear and well written; it is concise and easy to follow. The tables and figures are descriptive enough to communicate the methods and results.***

Thank you! We appreciate that you recognize the adequate structure and general content of our manuscript!

> ***The Introduction deals with the main aspect to place the study in context and contains relevant and updated citations to other published works. A minor observation is in line 69, where I suggest using "livestock" instead of "cattle" grazing, as livestock is a more general word to include the production of domestic animals, while cattle refers only to large rumiant animals, mainly with horns. Unless cattle are the only type of domestic animals for production in the four catchments, "livestock" seems to be a more appropriate term.***

We agree with your comment; and would replace the term "cattle" by "livestock".

> ***In general, the methodology is scientifically sounded, but I have some comments: The assessment of drought hazard seems to be straight forward. However, it would be useful if authors provide the time periods of analyses for each studied catchments, then the reader can have an idea of whether the periods are long enough to reflect the variability of the precipitation. It is not clear if they used the same period from all the catchments. Related to this, in line 144, authors mention they used a period from 1980-2018 to analyze CHIRPS data, but in line 156, they say they considered a period from 1980-2017.***

Thank you for this important hint. For the SPI calculation, we used the Chirps v2.0 precipitation data set with a common period from 1981-2018 for each of the four study catchments. We will correct the wrongly mentioned data period (1980-2017).

> ***Why did the authors only use the vegetation condition index to assess the vegetation condition within the drought hazard component? Why didn´t you use the Vegetation Health Index (VHI) which integrates the temperature condition (which can also be computed from MODIS data) in addition to vegetation index?***

We appreciate this comment and agree with Reviewer 1 that VHI has been widely applied in drought related research. VHI combines the Vegetation Condition Index (VCI) and the

Temperature Condition Index (TCI) that relates to evaporative demand. The validity of the VHI as drought assessment index is based on the assumption that the land surface temperature (LST) and the normalized difference vegetation index (NDVI) inversely vary over time (i.e., there is a negative NDVI-LST correlation) (Karnieli et al., 2010). Under drought periods, LST is expected to be high, while NDVI is expected to be low. However, some studies have shown that i) this negative correlation is not necessarily applicable everywhere (e.g., Smith and Choudhury 1991; Karnieli et al., 2006; Sun and Kafatos, 2007); and ii) there are often positive NDVI-LST correlations over the tropics and high latitudes, which represent areas where vegetation growth is energy limited (Nemani et al. 2003; Julien and Sobrino 2009). In humid regions (such as the tropics), increased temperatures may lead to increased plant biomass and height as confirmed by several studies through warming experiments (Van Wijk et al. 2003; Stow et al. 2004; Walker et al. 2006). We therefore decided to use VCI, which we consider suitable to detect vegetation related drought anomalies in the tropics, especially in tropical grassland ecosystems. We would include this explanation in a potential update of the manuscript.

> ***Vulnerability was computed using different freely available data sources which have different spatial resolutions. I suggest including these spatial resolutions in Table 2 to provide more information regarding these different data sources. Combining different sources with different spatial resolutions always represent a challenge for any spatial analysis. I am aware that authors used the best available spatial datasets regarding livestock, cropland and population densities, as well as data on roads and GDP. However, authors should consider adding some lines in their discussion regarding the way these different spatial resolutions may affect their results. I am aware that authors make a discussion regarding that more detailed data would be necessary to obtain better results at a more local scale (but may not be available or existent). Although they state in lines 218/219 that all grids were resampled to a common cell size, this does not mean that all grid layers contain the same level of detail. Thus, my suggestion is to discuss briefly about the implications of integrating different scales on their results.***

Thank you for this valuable hint, this information is indeed missing! We will include the spatial resolution information in Table 2 and incorporate a section in the discussion related to the influence of differing spatial resolutions and the expected implications of increasing spatial resolution on the results.

Table 2: Vulnerability related data sets

Population	Density	GHS Population Grid 2015	250m
Livestock	Density	Gridded Livestock of the World (GLW)	5km
Crop area	Density	Global Agricultural Lands 2000	1km
Proximity to Infrastructure	Euclidean distance	Major roads	30m
GDP PPP	GDP per capita	https://doi.org/10.5061/dryad.dk1j0	1km

The data sets were resampled to the highest resolution: 30m. This lowers the accuracy of the vulnerability information in the grid cells for the resampled data products, by transferring the same value of the lower resolution cells to all cells lying within the larger cell. This is especially relevant for livestock and crop density that showed more spatial variation. We will discuss the implications of resampling to a higher spatial resolution for each indicator in section 4.3.

> ***The results section contains enough description of the main findings and all maps, tables and figures are adequate.***

Thank you for this positive remark!

> ***In the Discussion section, authors start saying that they get "plausible" results. I suggest removing "plausible", as it seems that they were comparing their results to real data for validation, which is not the case. Authors did this only for the Muriaé catchment; therefore, I suggest following the same style they used to report results for the other catchments (in which they did not use "plausible").***

Thank you for this recommendation. We will remove the term "plausible" and change the sentence accordingly: "Our results were able to display drought risk hotpots in the Muriaé basin…"

> ***Although the Discussion is rich in the way the authors analyse and interpret their results, I found a lack of references to put their study in a more general context. For example, how is this approach to the evaluation of drought risk similar to other studies? Does this study have advantages or disadvantages compared to other drought risk studies? This would outline the utility of the approach presented in the manuscript.***

We agree that such a discussion would add more value to the manuscript. We would include a separate section on the strengths and weaknesses of our approach in the context of the wider literature.

Section 4.4: Drought risk assessment

Multiple assessment approaches have been developed to evaluate drought risk in regions worldwide; each of them strongly depending on site-specific drought hazard and vulnerability characteristics (Hall and Leng, 2019; Hagenlocher et al., 2019).

Vogt et al. (2018) distinguished between two main drought risk assessment classes: the "outcome or impact approach" and the "contextual or factor approach" (Brooks et al., 2003; González-Tánago et al., 2016, Naumann et al., 2018). The "outcome or impact approach" is based on quantitative data about historical impacts as proxies for vulnerability, and focusses on the expected losses due to a particular hazard (eg. Kumar and Panu, 1997; Stagge et al., 2015; Bachmair et al., 2015; Blauhut et al., 2015&2016). Regression models are used to determine the probability or "likelihood" of occurrence of an impact to occur in dependence of a drought hazard anomaly.

The "contextual or factor approach" combines hazard with exposed social and economic factors or assets as vulnerability proxies. The approach uses normalized and weighted

indicators/indices that describe the relative susceptibility of a location to damaging effects of a drought (e.g. Naumann et al., 2014&2019; Carrão et al., 2016).
Ideally both approaches should be combined; shortcomings – related to eg. limited data and their spatio-temporal resolution or arbitrary decisions related to weighting and data masking -- are discussed by the authors mentioned above and in Brooks et al. (2003), Vogt et al. (2018) and Hagenlocher et al. (2019).
Our study belongs to the “contextual or factor approach” category and suggests indicators to evaluate tropical drought risk under data scarcity. Rather than providing a generic approach, it evaluates the suitability of each individual index and gridded data set to be applied to four different tropical study regions. It attempts to address spatial variation of hazard in response to catchment characteristics and shorter but damaging tropical drought hazards.

I hope the authors and editor find my comments useful.

Yes! Thank you for this constructive feedback!

References

Bachmair, S., Svensson, C., Hannaford, J., Barker, L. J., and Stahl, K.: A quantitative analysis to objectively appraise drought indicators and model drought impacts, Hydrol. Earth Syst. Sci., 20, 2589–2609, https://doi.org/10.5194/hess-20-2589-2016, 2016.

Blauhut, V., Stahl, K., Stagge, J. H., Tallaksen, L. M., Stefano, L. de, and Vogt, J.: Estimating drought risk across Europe from reported drought impacts, drought indices, and vulnerability factors, Hydrol. Earth Syst. Sci., 20, 2779–2800, https://doi.org/10.5194/hess-20-2779-2016, 2016.

Brooks, N., 2003. Vulnerability, Risk and Adaptation: A Conceptual Framework. Working Paper 38, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich. https://gsdrc.org/document-library/vulnerability-risk-and-adaptation-a-conceptual-framework/

González-Tánago, I., Urquijo, J., Blauhut, V., Villarroya, F. and De Stefano, L.: Learning from experience: a systematic review of assessments of vulnerability to drought, Nat. Hazards, 80, 951–973, doi:10.1007/s11069-015-2006-1, 2016.

Hagenlocher, M., Meza, I., Anderson, C. C., Min, A., Renaud, F. G., Walz, Y., Siebert, S., and Sebesvari, Z.: Drought vulnerability and risk assessments: state of the art, persistent gaps, and research agenda, Environ. Res. Lett., 14, 83002, https://doi.org/10.1088/1748-9326/ab225d, 2019.

Hall, JW. Leng, G., 2019. Can we calculate drought risk… and do we need to? Wiley WIRE Water, https://doi.org/10.1002/wat2.1349

Julien, Y., and J. A. Sobrino, 2009: The Yearly Land Cover Dynamics (YLCD) method: An analysis of global vegetation from NDVI and LST parameters. Remote Sens. Environ., 113, 329–334.

Karnieli, A., Agam, N., Pinker, R.T., Anderson, M., Imhoff, M.L., Gutman, G.G., Panov, N. and Goldberg, A., 2010. Use of NDVI and land surface temperature for drought assessment: Merits and limitations. Journal of climate, 23(3), pp.618-633.

Karnieli, A., M. Bayasgalan, Y. Bayarjargal, N. Agam, S. Khudulmur, and C. J. Tucker, 2006: Comments on the use of the vegetation health index over Mongolia. Int. J. Remote Sens., 27, 2017– 2024.

Kumar and V., Panu, U., 1997. Predictive assessment of severity of agricultural droughts based on agro-climatic factors. J. Am. Water Resour. Assoc. 33 (6), 1255–1264.

Naumann, G., Barbosa, P., Garrote, L., Iglesias, A., Vogt, J.: Exploring drought vulnerability in Africa: an indicator based analysis to be used in early warning systems. Hydrol. Earth Syst. Sci. 18, 1591–1604, 2014.

Naumann, G., Vargas, W., Barbosa, P., Blauhut, V., Spinoni, J., and Vogt, J.: Dynamics of Socioeconomic Exposure, Vulnerability and Impacts of Recent Droughts in Argentina, Geosciences, 9, 39, https://doi.org/10.3390/geosciences9010039, 2019.Nemani, R., and S. Running, 1989: Estimation of regional surface resistance to evapotranspiration from NDVI and thermal-IR AVHRR data. J. Appl. Meteor., 28, 276–284.

Smith, R. C. G., and B. J. Choudhury, 1991: Analysis of normalized difference and surface temperature observations over southeastern Australia. Int. J. Remote Sens., 12, 2021–2044.

Stow, D. A., and Coauthors, 2004: Remote sensing of vegetation and land-cover change in Arctic tundra ecosystems. Remote Sens. Environ., 89, 281–308.

Sun, D., and M. Kafatos, 2007: Note on the NDVI-LST relationship and the use of temperature-related drought indices over North America. Geophys. Res. Lett., 34, L24406, doi:10.1029/ 2007GL031485.

Van Wijk, M. T., M. Williams, J. A. Laundre, and G. R. Shaver, 2003: Interannual variability of plant phenology in tussock tundra: Modelling interactions of plant productivity, plant phenology, snowmelt and soil thaw. Global Change Biol., 9, 743–758.

Vogt, J., Naumann, G., Masante, D., Spinoni, J., and Barbosa, P.: Drought Risk Assessment and Management. A Conceptual Framework, https://doi.org/10.2760/919458, available at: https://www.researchgate.net/publication/329451050_Drought_Risk_Assessment_and_Management_A_Conceptual_Framework, 2018.

Walker, M. D., and Coauthors, 2006: Plant community responses to experimental warming across the tundra biome. Proc. Natl. Acad. Sci. USA, 103, 1342–1346.