Evaluating drought risk in data scarce tropical environments

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Abstract

Droughts are a recurrent phenomenon in water abundant tropical countries worldwide and are expected to become more frequent in the future. However, drought risk in tropical catchments is poorly understood and usually not adequately incorporated in water management strategies. Thus, methodologies to evaluate spatial and seasonal drought risk in data scarce tropical catchments are urgently needed. We combined hazard and vulnerability related information to assess drought risk in the test basin, the rural Muriaé basin in southeast tropical Brazil. Hazard indicates the cumulative frequency of drought anomalies, while vulnerability represents the potential of a drought to cause damages in the socioeconomic system. We simulated subcatchment discharges with a hydrological model (SWAT) to evaluate spatially distributed hydrological drought hazard and combined this information with precipitation and vegetation based indices to define the cumulative frequency of drought occurrence for each grid cell (0.1°). We tested the sensitivity of different climate and catchment related model input variables against low flow events and simulated artificial drought risk scenarios. To assess vulnerability, we reclassified and weighted globally and regionally available gridded socioeconomic data. Vulnerability in the downstream area was found to be stronger which coincided with a higher hydrological and vegetation based hazard. The drought risk map clearly identified the downstream area of the Muriaé basin as being exposed to a stronger drought risk compared to the upstream areas. Only limited hydrological drought sensitivity of the system against changes in land cover type and temperature was shown in the model results while geology and soils turned out to play a larger role for low flows. The drought scenarios showed that low flows were more severely affected than high flows by climatic changes such as decreased precipitation. In can be concluded that our risk assessment methodology offers a holistic, science based and innovative solution to inform regional planning and water management institutions dealing with the control of drought disasters in tropical rural areas. Such drought risk evaluation frameworks and spatial information are urgently needed in tropical regions worldwide.

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Introduction

BACKGROUND

- Tropical droughts are poorly understood
- Southeastern Brazil was affected by a long term drought during the period Jan 2014 – Dec 2015
- Strong implications for domestic water supply, the hydropower sector and agricultural production.
- Rural areas were extremely impacted due to the lack of storage or infrastructure (rainfed agriculture, livestock)
- There is a lack of methods to assess tropical drought risk.

OBJECTIVES

The overall aim of this study is to assess tropical drought risk hotspots in rural and data scarce tropical catchments. Specific objectives are

1. To assess site-specific drought hazard
2. To understand spatial and sector related drought vulnerability
3. To visualize spatial distribution of drought risk in the Muriaé basin, Brazil.

STUDY AREA: MURIAÉ RIVER BASIN

- Size: 8292 km^2
- Shared by the Federal States Minas Gerais and Rio de Janeiro.
- Strongly seasonal tropical savanna climate (hot and rainy summer)
- Suffers from hydro-meteorological extremes as floods and droughts
- Topography: Elevation: 10 – 2000 m.a.sl.
- Land use: 65% pasture, 20% forest, 9% agriculture and 2.3% urban (Künne et al., 2016)

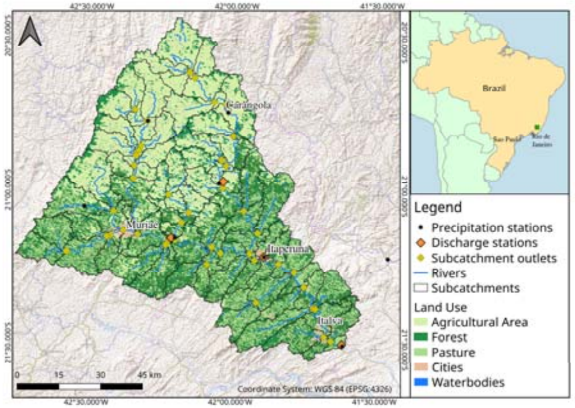

***Figure 1**: The Muriaé catchment, its location in Brazil, topography, river network, discharge stations and simulated discharge points (subcatchment outlet)*

DATA AND METHODS

Precipitation data: Satellite based rainfall estimate (SRE) Chirps v2.0 for the period 2000-2015. Selection based on point to pixel evaluation (Baez et al., 2018) and rainfall runoff modelling (SWAT and TUW model) of several SREs (Nauditt et al., 2018).

Discharge data: 4 discharge stations (ANA, 2017) for SWAT 2012 calibration. 93 simulated sub-basin discharges (SWAT 2012)

Vegetation: MODIS MOD13Q13, NDVI composite 16-day and 250m July 2015

Vulnerability data : Population-, livestock- and crop densities, socio-economic, demographic and infrastructural gridded data (Table 2)

All datasets were resampled using the nearest neighbor method to account for differences in pixel resolution of the datasets prior to reclassification.

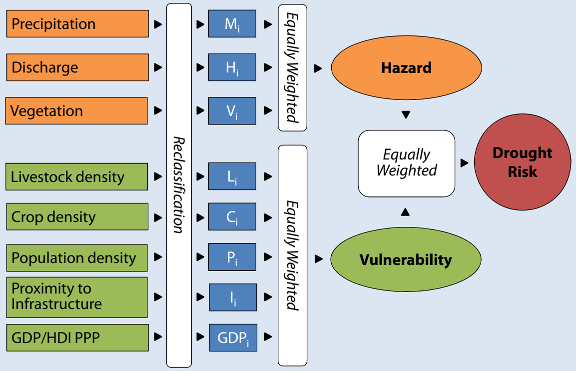

***Figure 2:** Methodological concept and drought indicators*

Methods

HAZARD ASSESSMENT

Drought Hazard $= \dfrac{H_i + M_i + V_i}{3}$

- Hydrological index H_i: cumulative drought duration reclassified in 7 severity categories (Table 1). Due to the lack of spatially distributed discharge stations in the Muriaé catchment (Figure 1), we calibrated the rainfall-runoff model SWAT2012 (Neitsch et al., 2011) and derived 93 subcatchments to simulate discharges for each outlet.
- Meteorological Index M_i : cumulative drought duration reclassified in 7 severity categories. Number of events >=5 days below 0.5 mm of precipitation (Chirps v2.0).
- Vegetation based index V_i : drought severity reclassified in 7 categories of VCI values for the driest event basin-wide (July 2015).

***Table 1:** Hazard indicator classification and rating. The higher the rating value, the drier.*

Hazard Indicator	Classification	Rating
H_i Streamflow Threshold (>=5 days below daily variable Q_{20})	7	1
	8	2
	9	3
	10	4
	11	5
	12	6
	13	7
M_i Precipitation Threshold (0.3 mm >= 5 days)	< 245	1
	245-265	2
	265-285	3
	285-305	4
	305-325	5
	325-345	6
	> 345	7
V_i Vegetation Condition Index (VCI)	> 50	1
	40-50	2
	30-40	3
	20-30	4
	10-20	5
	< 10	6

VULNERABILITY

Drought Vulnerability = $\dfrac{L_i + C_i + P_i + I_i + GDP_i}{5}$

- We use five socioeconomic indicators to represent spatial drought vulnerability in the Muriaé basin.
- Gridded datasets are evaluated according to a rating system that is based on a drought related data classification.
- The higher the rating value, the stronger the drought vulnerability (Table 2).

***Table 2:** Vulnerability indicator classification, rating and weighting*

Indicator	Classification	Rating	Data/ Source
L_i Livestock density (head per km^2)	> 25	1	Gridded Livestock of the World (GLW); Robinson et al., 2014
	25 – 50	2	
	51 – 100	3	
	> 100	4	
C_i Cropland (% area)	0-0.1	1	Global Agricultural Lands 2000, Ramankutti et al, 2008.
	0.1-0.2	2	
	0.2-0.5	3	
	0.5-1	4	
P_i Population Density (people/pixel)	<50	1	GHS Population Grid 2015; CIESIN, 2015
	50-200	2	
	200-500	3	
	500-1500	4	
	>1500	5	
I_i Proximity to Infrastructure (km)	< 100	1	Major roads, CIESIN, 2013
	100 - 1000	2	
	> 1000	3	
GDP_i GDP (million USD)	<1	5	GriVulnerability dded global GDP/HDI, Kummu et al., 2018
	1-2	4	
	2-5	3	
	5-20	2	
	>20	1	

Results & Conclusion

DROUGHT HAZARD

Drought hazard is highest in the southwestern downstream part of the Muriaé basin. Detailed results suggest that this can be attributed to a higher cumulative hydrological and meteorological drought duration and a strong vegetation dryness anomaly in the downstream part. Also the western part is hazard prone due to lower rainfall and drier than normal vegetation.

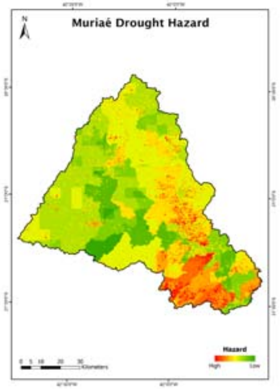

***Figure 3 :** Drought Hazard in the Muriaé subbasin.*

VULNERABILITY

Figure 4 shows an almost basin-wide strong vulnerability to drought. Detailed results and observations reveal that this might be due to either crop or livestock density combined with low GDP of rural population and long distances to infrastructure, or high population density in urban settlements.

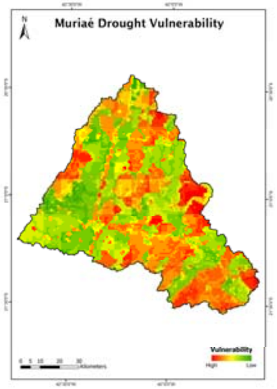

***Figure 4 :** Drought Vulnerability in the Muriaé*

DROUGHT RISK

Figure 5 shows that drought risk is strong in the downstream southern region of the basin due to both, high hazard and vulnerability. The drier and more vulnerable northeastern region is exposed to a higher risk than the wetter, less vulnerable west.

Strong drought vulnerability in the Northeastern part is outweighted by the low hazard values in the agricultural region.

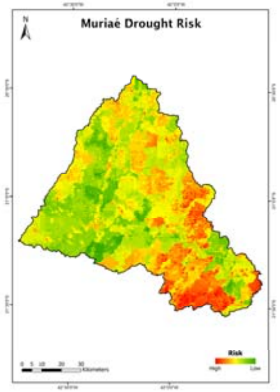

***Figure 5:** Drought Risk map of the Muriaé basin. Produced by equally weighting drought hazard and vulnerability values for each pixel.*

CONCLUSION

The presented risk assessment methodology for data scarce and rural tropical areas offers a holistic, science based and innovative solution to provide relevant drought related information. A further step will be to validate the final risk map with independent information and/or test it against stakeholder perception. Then it will make a valuable contribution to regional planning by water management institutions dealing with the control of future drought disasters in tropical rural areas.