INTEGRATED ASSESSMENT OF LIVESTOCK PRODUCTION-RELATED WATER SCARCITY IN SANTA CATARINA, BRAZIL

Fiorina-Marie Telesca [1], Katrin Drastig [2] & Pedro Luiz Borges Chaffe[3]

Key Words – Livestock production, water scarcity footprint, water stress, methodological sensitivity, integrated assessment.

INTRODUCTION

Increasing drought induced water scarcity poses major challenges for sustainable water resources management and directly affects food production regions (Carra et al., 2023). In Santa Catarina, southern Brazil, livestock production represents an important water use sector. Identifying livestock production related water scarcity hotspots is therefore important for prioritising catchments for water management and drought adaptation (Exterckoter et al., 2015).

However, livestock water scarcity assessments are highly sensitive to methodological choices (Quinteiro et al., 2018). Water scarcity indicators are continuous metrics, so defining scarcity events requires thresholds that are not universal (Hess et al., 2015). Indicator selection, event definitions, scarcity gates and hotspot thresholds can therefore alter the extent and spatial distribution of priority areas. Assessments based on one single set of methodological choices may also overlook temporal variability, reducing confidence under changing hydrological and production conditions (Liu et al., 2017). tests methodological sensitivity by comparing alternative combinations of indicators, event definitions, scarcity gates and hotspot tiers, and integrates recurrence, methodological continuity, indicator agreement, livestock contribution, temporal trends and hydrological scale to provide a more comprehensive interpretation of hotspot status and its management relevance. Following FAO LEAP guidelines (2019), the assessment applies the AWARE 2.0 based Water Scarcity Footprint based (*WSF*), according to Seitfudem et al. (2025) and SDG Indicator 6.4.2 Level of Water Stress (*WS*) according to Vanham et al. (2018) at monthly catchment scale.

METHODOLOGY

Monthly livestock water scarcity was assessed for 80 drainage areas defined by CAMELS BR gauges that intersect Santa Catarina. Daily streamflow records from the CAMELS BR dataset for January 1995 to October 2024 were converted to monthly volumes (Chagas et al., 2020). Several gauges lie on the same river networks, so their drainage areas overlap. These gauges were analysed separately to retain variation across drainage scales but interpreted jointly as connected systems. Municipal livestock consumption, livestock withdrawals and total withdrawals were obtained from ANA (2019), where values were allocated to drainage areas in proportion to the area of each municipality intersecting each catchment. Environmental water requirements (*EWR*) were estimated for each catchment and month using the variable monthly flow method of Pastor et al. (2014), as adapted for AWARE 2.0 by Seitfudem et al. (2025).

For WSF, local Availability Minus Demand (*AMD*) was calculated as the water remaining after *EWR* per unit catchment area, $AMD = (Q - EWR)/Area$, where Q denotes observed monthly streamflow. The catchment- and month-specific AWARE characterisation factor (CF_{AWARE}) was then calculated as the AWARE world reference of 0.0136 $m^3\ m^{-2}\ month^{-1}$ divided by local *AMD*. Values were bounded between 0.1 and 100, with CF_{AWARE} set to 100 when *AMD* was zero.

1) Master in Integrated Natural Resource Management, Humboldt-Universität zu Berlin, Germany, fiorinatelesca@gmail.com
2) Leibniz Institute for Agricultural Engineering and Bioeconomy, Potsdam, Germany, kdrastig@atb-potsdam.de
3) Department of Sanitary and Environmental Engineering, Federal University of Santa Catarina, Florianópolis, Brazil, pedro.chaffe@ufsc.br

The WSF was subsequently calculated by multiplying monthly livestock water consumption (*LWC*) by this locally derived factor (Boulay et al., 2018):

$$WSF = LWC \times CF_{AWARE}[m^3\ world - eq\ month^{-1}]$$

For WS, the water remaining after *EWR* was expressed as allocable water and calculated as $WA = \max(Q - EWR, 0)$. Livestock water stress was then calculated by relating water withdrawals for livestock production (WW_{liv}) to *WA* as follows:

$$WS_{liv} = 100\ \frac{WW_{liv}}{WA}\quad [\%]$$

Using total water withdrawals in the same calculation produced WS_{tot}, the percentage of allocable water withdrawn by all sectors in the catchment. Livestock contribution expresses livestock withdrawals as a share of total withdrawals and was calculated as $C_{liv} = 100 \cdot WS_{liv}/WS_{tot}$.

Methodological sensitivity was tested by varying the definitions of events, scarcity gates and hotspots. Event thresholds identified elevated monthly indicator values. Scarcity gates retained the subset of events that also occurred under selected total catchment scarcity conditions, indicated by CF_{AWARE} and WS_{tot} gates. Hotspot tiers then determined how recurrent those events had to be relative to other gauges. For *WSF*, pooled p80, p90, p95 and p99 thresholds across all monthly values represented increasingly high footprint values. Each was tested without a gate and with CF_{AWARE} values of at least 2, 4 and 10. For WS_{liv}, fixed event thresholds of 10%, 20%, 30% and 40% were tested without a gate and with WS_{tot} of at least 50%, 75% and 100%. The p80, p90, p95 and p99 quantiles of each ungated cross gauge event frequency distribution defined increasingly selective hotspot tiers and were retained for the corresponding gated tests.

Each indicator therefore contributed 4 event definitions × 4 gates × 4 hotspot tiers, which produced 64 classifications per gauge. Methodological continuity measured the percentage of these configurations in which a catchment retained hotspot status and distinguished classifications that persisted across design choices from those tied to only a few definitions. Combined continuity used all 128 classifications from both indicators. Continuity therefore reflects stability under method choice, whereas event frequency reflects recurrence over time. Indicator overlap identified catchments classified by both *WSF* and *WS*. Mann–Kendall tests and Sen's slope assessed the direction and significance of changes in annual mean values. Finally, occurrence, continuity, overlap, C_{liv}, significant trends and connected hydrological scale were interpreted together to inform differentiated management responses.

RESULTS

Across 26,517 monthly records, hotspot classifications changed substantially with indicator, event definition, scarcity gate and hotspot tier. *WSF* produced 186 positive classifications across 21 gauges, whereas *WS* produced 182 across only six. Similar classification totals therefore concealed very different spatial patterns. All six *WS* hotspot gauges were also identified by *WSF* and therefore constituted the six indicator-overlap catchments. Figure 1 presents the resulting spatial synthesis, highlighting the different water-scarcity conditions identified across the study area.

Among the shared hotspots, Passo Pio X showed the clearest convergence of evidence. It was the only gauge to record WS_{liv} events in several months while allocable water remained above zero, with 11, 7, 4 and 2 observations above 10%, 20%, 30% and 40%, respectively. Livestock supplied 54.24% of withdrawals across its 11 events, while mean event WS_{liv} was 26.22% and mean WS_{tot} was 48.32%. Passo Pio X also remained a *WSF* hotspot under higher CF_{AWARE} gates, indicating that elevated *WSF* coincided with locally scarce conditions. Its high methodological continuity, indicator agreement and

significant increases under both indicators together identified it as the strongest recurrent, livestock-driven and intensifying priority.

The remaining shared hotspots reflected distinct conditions with different management implications. Warnow and Indaial each experienced a single month without allocable water after *EWR*. The resulting unbounded *WS* values caused the same extreme observation to qualify under several cumulative thresholds, gates and hotspot tiers. Their high *WS* continuity therefore reflected methodological repetition of one extreme month rather than recurrent events over time, and livestock contribution could not be calculated for those events. Warnow showed no significant upward trend and therefore represented an existing priority without evidence of worsening, whereas Indaial on the other hand did show significant increases. At Turvo and Pirabeiraba, livestock contributed less than 1% during severe events, indicating multi-sector rather than livestock-dominated crises. Passo Quilombo had a livestock share of 44.15% during one event, but the event did not meet a WS_{tot} gate, did not recur and rarely coincided with a *WSF* classification across methodological pairs. It was therefore retained as a conditional livestock-related signal.

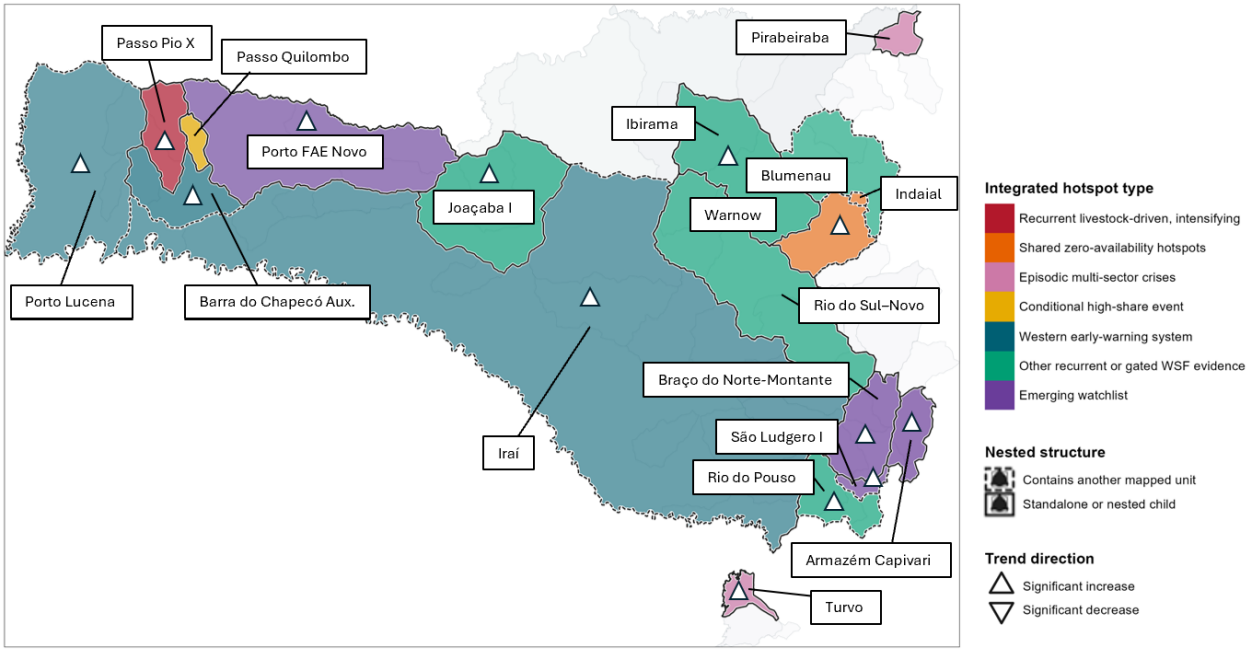


Figure 1. *Integrated spatial synthesis of water-scarcity conditions related to livestock production. Only catchments retained in the integrated interpretation are shown. Trend symbols mark significant trends amongst catchments discussed in the results.*

The integrated assessment also identified preventive and emerging priorities beyond the six shared hotspots. Iraí, Porto Lucena and Barra do Chapecó Aux. form the connected western system. Across its drainage scales, livestock contribution ranged from 31.13% to 44.39% while *WSF* was recurrent or increasing, but mean WS_{tot} remained only 0.14% to 0.25%. This combination indicates a potential early warning rather than a current high stress crisis. Rio do Pouso, Joaçaba I, Rio do Sul-Novo, Ibirama and Blumenau (PCD) were repeatedly classified as *WSF* hotspots under varying methodological configurations and CF_{AWARE} gates, though they were not *WS* hotspots. Rio do Sul-Novo and Ibirama are part of the eastern connected system with Warnow and Indaial, so these results show how the *WSF* signal persists across connected drainage scales. The combination of significant upward trends and low current continuity placed Porto FAE Novo in the western system, the connected southeastern pair Braço do Norte–Montante and São Ludgero I, and Armazém Capivari on the emerging watchlist.

CONCLUSION

The integrated assessment identified Passo Pio X as the clearest overall water scarcity priority related to livestock production. The other highlighted catchments revealed different management needs, including coordination during multi sector crises, monitoring of zero availability vulnerability, preventive action in livestock relevant but currently low stress systems and surveillance of emerging trends. These distinctions provide more useful management information than a binary hotspot classification.

The broader learning is that hotspot status cannot be separated from the methodological choices used to produce it. Interpreting recurrence, methodological continuity, indicator agreement, livestock contribution, trends and hydrological scale together reveals why, under which conditions and how consistently a catchment warrants attention, while retaining the uncertainty created by definition choice. The results support screening and prioritisation rather than causal attribution or prescribed interventions. Future research should test broaden the sensitivity assessment by testing a wider range of indicators, event definitions, gates, hotspot thresholds and input assumptions. It should also distinguish animal types and production systems so that management responses can be targeted more precisely.

REFERENCES

AGÊNCIA NACIONAL DE ÁGUAS (ANA). (2019). Manual de usos consuntivos da água no Brasil. ANA.

BOULAY, A.-M. et al. (2018). “The WULCA consensus characterization model for water scarcity footprints: Assessing impacts of water consumption based on available water remaining (AWARE)”. The International Journal of Life Cycle Assessment, 23, 368–378.

CARRA, S. H. Z. et al. (2023). “Impact assessment of livestock production on water scarcity in a watershed in southern Brazil”. Water, 15(22), 3955.

CHAGAS, V. B. P. et al. (2020). “CAMELS-BR: Hydrometeorological time series and landscape attributes for 897 catchments in Brazil”. Earth System Science Data, 12(3), 2075–2096.

EXTERCKOTER, R. K.; DA SILVA, C. A.; TULLA I PUJOL, A. F. (2015). “Family farmers as agents of resilience in the western region of Santa Catarina (Brazil)”. Ager, 18, 115–138.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). (2019). Water use in livestock production systems and supply chains: Guidelines for assessment. Version 1. LEAP Partnership.

HESS, T. M.; LENNARD, A. T.; DACCACHE, A. (2015). “Comparing local and global water scarcity information in determining the water scarcity footprint of potato cultivation in Great Britain”. Journal of Cleaner Production, 87, 666–674.

LIU, J. et al. (2017). “Water scarcity assessments in the past, present, and future”. Earth’s Future, 5(6), 545–559.

PASTOR, A. V. et al. (2014). “Accounting for environmental flow requirements in global water assessments”. Hydrology and Earth System Sciences, 18, 5041–5059.

QUINTEIRO, P. et al. (2018). “Identification of methodological challenges remaining in the assessment of a water scarcity footprint: A review”. The International Journal of Life Cycle Assessment, 23, 164–180.

SEITFUDEM, G. et al. (2025). “The updated and improved method for water scarcity impact assessment in LCA, AWARE2.0”. Journal of Industrial Ecology, 29(3), 891–907.

VANHAM, D. et al. (2018). “Physical water scarcity metrics for monitoring progress towards SDG target 6.4: An evaluation of indicator 6.4.2 ‘Level of water stress’”. Science of the Total Environment, 613–614, 218–232.