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Supplement of

Critical assessment of metrics and methods used to quantify temporal loading of rainfall events

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Supplementary Material

S1 Literature review: search and selection strategy

The literature review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Moher et al., 2010). The PRISMA framework is a standardised method of performing literature review which aims to minimise potential researcher bias, and to promote transparency and reproducibility in the identification and selection of relevant studies. The framework includes four key stages: (1) identification, boolean queries used to identify potential studies, duplicated studies removed; (2) screening, abstract level review to remove irrelevant studies; (3) eligibility, full-text review against pre-defined inclusion/exclusion criteria; and (4) inclusion, relevant studies included for review, and the total number of studies reported.

Boolean queries are search strings using AND, OR and NOT operators, and are constructed here by combining different terms used in the literature to describe event temporal loading, with different terms used to describe rainfall events. The full queries used to search the Scopus, Web of Science, and Google Scholar databases are outlined below:

– Scopus supports proximity operators (e.g., W/n requires two words to appear within n words of each other; Pre/n requires one word to precede the other within n words), a feature not available in the other databases. As such, for Scopus the search term was: [(("rainfall event" OR "precipitation event" OR "rain storm" OR "rainstorm" OR "storm event" OR ((‘precipitation" OR "rain" OR "rainfall" OR "storm") PRE/3 "event")) OR (("precipitation varia*" OR "rainfall varia*") W/1 "intra-event")) W/5 ("rainfall profile" OR "temporal pattern" OR "temporal distribution" OR "event loading" OR "temporal profile" OR "temporal loading" OR "intensity profile" OR (("precipitation pattern" OR "rainfall pattern") W/3 "temporal"))]

– For Web of Science and Google Scholar, it was: ("rainfall event" OR "precipitation event" OR "rain storm" OR "rainstorm" OR "storm event" OR ("precipitation" OR "rain" OR "rainfall" OR "storm") AND "event" OR ("precipitation varia*" OR "rainfall varia*") AND "intra-event") AND ("rainfall profile" OR "temporal pattern" OR "temporal distribution" OR "event loading" OR "temporal profile" OR "temporal loading" OR "intensity profile" OR ("precipitation pattern" OR "rainfall pattern") AND "temporal")].

The searches were performed on the 15/02/2025 and returned 903 relevant records overall (including 181 on Scopus, 409 on Web of Science, and 313 on Google Scholar). 351 duplicated records were removed, leaving 552 studies for abstract level screening. After screening of abstracts, a further 390 studies were eliminated, leaving 162 papers for full review.

Studies were included if they met the following criteria: (a) use of search terms in the title, abstract, or keywords; (b) published in English; (c) focus on individual rainfall events with data at sub-daily temporal resolution; (d) application of a method or metric to quantify temporal loading. Exclusion criteria were: (a) not published in English; (b) inaccessible or behind paywalls (to the authors, not all included studies are open-access); (c) lack of use of sub-daily rainfall data; (d) combined spatial and temporal analysis (where the temporal loading could not be separated); (e) focus on rainfall trends over extended periods (e.g., seasonal or monthly scales); (f) no application of a metric for quantifying within-event temporal variability.

After applying these criteria, a total of 59 studies remained. We note, however, that several additional studies met all criteria except the use of a metric to quantify temporal loading. These excluded studies fall into three main groups. The first concerns the disaggregation of daily rainfall data (Pampaloni et al., 2021). The second includes stochastic event generation approaches (Cha et al., 2024; Efstratiadis et al., 2022; Kao and Govindaraju, 2008; Nguyen and Chen, 2022; Oriani et al., 2018; Pampaloni et al., 2021). The third involves applications of synthetic rainfall events with prescribed temporal patterns to investigate impacts on soil erosion (De Lima and Singh, 2002; de Lima et al., 2013; Frauenfeld and Truman, 2004; Gao et al., 2018; Parsons and Stone, 2006; Wang et al., 2023), landslides (Zhao et al., 2025), and herbicide runoff (Zhang et al., 1997). In these cases, event profiles are described using broad qualitative labels (e.g. linearly increasing, stepped increasing–decreasing, uniform) rather than being quantified with explicit metrics.

S2 Selected papers

Table S1. Summary of reviewed papers

Authors	**Metric type**	**Metric**	**Study purpose**	**Rainfall**	**Processing**
Amin et al. (2000)	Classification	*4th with most*	Characterising typical profiles in an area	Real	DMC
Aquino et al. (2013)	Classification	*3rd with peak*	Impact of storm temporal pattern on soil erosion	Real	Raw
Asher et al. (2025b)	Classification	*5th with most*	Impact of storm temporal pattern on flood risk	Synthetic	DMC
Azli and Rao (2010)	Classification	*4th with most*	Characterising typical profiles in an area	Real	DMC
Back and Rodrigues (2021)	Classification	*4th with peak*	Characterising typical profiles in an area	Real	Unclear
Bezak et al. (2018)	Classification	*4th with most*	Impact of storm temporal pattern on hydraulic model outcomes	Synthetic	DMC
Brommer et al. (2013)	Continuous	*mean, (C) std, (C) skewness, (C) kurtosis*	Characterising typical profiles in an area	Real	Raw
Cai et al. (2024)	Continuous	*Peak position ratio, PCI*	Impact of storm temporal pattern on peak runoff generation	Synthetic	Raw
Chen et al. (2015)	Classification	*4th with most*	Characterising typical profiles in an area	Real	Unclear
de Assunção Montenegro et al. (2018)	Classification	*3rd with peak*	Impact of storm temporal pattern on soil moisture patterns	Real	Raw
de Andrade et al. (2020)	Classification, Continuous	*3rd with peak*, *I30*	Impact of storm temporal pattern on soil erosion	Real	Raw
Dolšak et al. (2016)	Classification	*4th with most*, *BSC*	Characterising typical profiles in an area	Real	DMC
Dunkerley (2015)	Continuous	*Intermittency fraction*	Developing methods for describing temporal profile	Real	Raw
Dunkerley (2021b)	Continuous	*Intermittency fraction*	Developing methods for describing temporal profile	Real	Raw
Fan et al. (2020)	Continuous	*(C) skewness, (C) kurtosis*	Impact of storm temporal pattern on landslides	Synthetic	Raw

Authors	**Metric type**	**Metric**	**Study purpose**	**Rainfall**	**Processing**
Fatone et al. (2021)	Classification	*3rd with peak*	Impact of storm temporal pattern on hydrograph outflow	Real	DMC
Fu et al. (2021)	Continuous	*Coefficient peak rainfall intensity*, *3rd with ppr*	Impact of typhoon temporal pattern on pollution generation	Real	Raw
Gao et al. (2024)	Continuous	*Relative amplitude*	Impact of storm temporal pattern on soil erosion	Real	Raw
García-Bartual and Andrés-Doménech (2017)	Continuous	*(C) kurtosis*, *(C) standard deviation*	Characterising typical profiles in an area	Real	Raw
Garcia-Guzman and Aranda-Oliver (1993)	Classification	*4th with most*	Characterising typical profiles in an area	Real	DMC
Ghanghas et al. (2024)	Continuous	*Event Loading Index*	Impact of climate on temporal pattern	Real	Raw
He et al. (2022)	Continuous	*PCI*	Characterising typical profiles in an area	Synthetic	Raw
He et al. (2024)	Continuous	*(C) skewness*, *(C) kurtosis*	Impact of storm temporal pattern on slope instability	Synthetic	Raw
Horner and Jens (1942)	Classification	*3rd with peak*	Impact of storm temporal pattern on surface runoff	Real	Unclear
Hu et al. (2018)	Continuous	*Gini coefficient*, *Lorenz coefficient*	Changes to temporal inequality of daily precipitation over last 50 years	Synthetic	Raw
Huff (1967)	Classification	*4th with most*	Characterising typical profiles in an area	Real	DMC
Jeon et al. (2017)	Classification	*4th with most*	Impact of storm temporal pattern on water quality from storm runoff	Synthetic	DMC
Jun et al. (2021)	Classification Continuous	*4th with most*, *time to peak*	Characterising typical profiles in an area	Real	Unclear
Knighton and Walter (2016)	Continuous	*T25 / 50 / 75*, *time to peak*	Stochastic event generation	Real	DMC
Li et al. (2023)	Continuous	*Peak-mean ratio*, *peak position ratio*	Evaluating satellite precipitation products	Real	Raw
Liang et al. (2023)	Classification	*3rd with most*	Impact of storm temporal pattern on soil erosion	Synthetic	DMC

Li et al. (2021)	Classification	*4th with most*	Characterising typical profiles in an area; Impact of storm temporal pattern on sewer overflows	Real	Raw
Liu et al. (2022)	Continuous	*Relative amplitude*, *% rain HIZ*, *% time in HIZ / LIZ*	Impact of storm temporal pattern on runoff and soil loss	Real	Raw
Long et al. (2021)	Continuous	*TCI*	Impact of climate on temporal (and spatial) pattern	Real	Unclear
Loveridge et al. (2015)	Classification	*3rd with D50*	Characterising typical profiles in an area	Real	DMC
Lu and Qin (2020)	Classification	*4th with most*	Impact of storm temporal pattern on urban drainage	Synthetic	DMC
Müller et al. (2017)	Continuous	*Asymmetry of dependence*	Impact of storm temporal patterns on sewer flow simulations	Real	Raw
Nel (2007)	Classification	*4th with peak*	Characterising typical profiles in an area; Impact of storm temporal pattern on runoff and soil erosion	Real	DMC
Oh et al. (2024)	Continuous	$NRMSE_p$ and $Skew_p$	Impact of storm temporal pattern on peak flood discharge	Real	Unclear
Pandey et al. (2025)	Continuous	*Intermittency fraction*	Impact of climate on temporal pattern	Real	Raw
Pinheiro et al. (2018)	Classification	*3rd with peak*	Characterising typical profiles in an area; Impact of storm temporal pattern on soil erosion	Real	DMC
Pohle et al. (2018)	Continuous	*Event dry ratio*, *Frac. in Q1 / Q2 / Q3 / Q4*	Stochastic event generation	Synthetic	Raw
Terranova and Iaquinta (2011)	Classification	*BSC*	Characterising typical profiles in an area	Real	DMC
Tian et al. (2017)	Continuous	*CV*	Stochastic event generation	Synthetic	Raw
Todisco (2014)	Classification	*CV*, *Run number*	Developing methods for describing temporal profile; Impact of storm temporal pattern on soil erosion	Real	Raw
Tsubo et al. (2005)	Classification	*4th with peak*	Characterising typical profiles in an area	Real	DMC

Serna and Taipe (2019)	Classification	*3rd with peak*	Characterising typical profiles in an area	Real	DMC
Schiff (1943)	Classification	*3rd with peak*	Impact of storm temporal pattern on infiltration and runoff	Real	DMC
Varga et al. (2009)	Classification	*3rd with CoG*	Developing methods for describing temporal profile	Real	DMC
Vantas et al. (2019)	Classification	*4th with most*	Developing methods for describing temporal profile	Real	Raw
Villalobos Herrera et al. (2023)	Classification	*5th with most*	Characterising typical profiles in an area	Real	DMC
Visser et al. (2023)	Continuous	D_{50}	Impact of climate on temporal pattern	Real	DMC
Wang et al. (2016)	Classification	*3rd with peak*	Impact of storm temporal pattern on soil erosive loss	Real	DMC
Wang et al. (2018)	Classification	*3rd with ppr*	Impact of storm temporal pattern on soil water transport	Real	DMC
Yang et al. (2015)	Continuous	*Coefficient of variability*	Assessing performance of data assimilation on events with different temporal loading characteristics	Real	Raw
Yang et al. (2022)	Continuous	*Peak position ratio*	Characterising typical profiles in an area Regional patterns in temporal profile	Real	Raw
Yang et al. (2024)	Classification	*5th with peak*	Impact of storm temporal pattern on flash flooding	Real	Unclear
Yin et al. (2016)	Classification	*4th with peak*	Characterising typical profiles in an area	Real	DMC
Wartalska et al. (2020)	Continuous	*m1*, *m2*, *m3*, *m4*, *m5*, *peak position ratio*	Characterising typical profiles in an area	Real	DMC
Wartalska and Kotowski (2020)	Continuous	*m4*, n_i	Characterising typical profiles in an area; Impact of future climate on typical profiles.	Real	DMC
Williams-Sether (2004)	Classification	*4th with most*	Characterising typical profiles in an area	Real	DMC

S3 Summary of reviewed literature and metrics

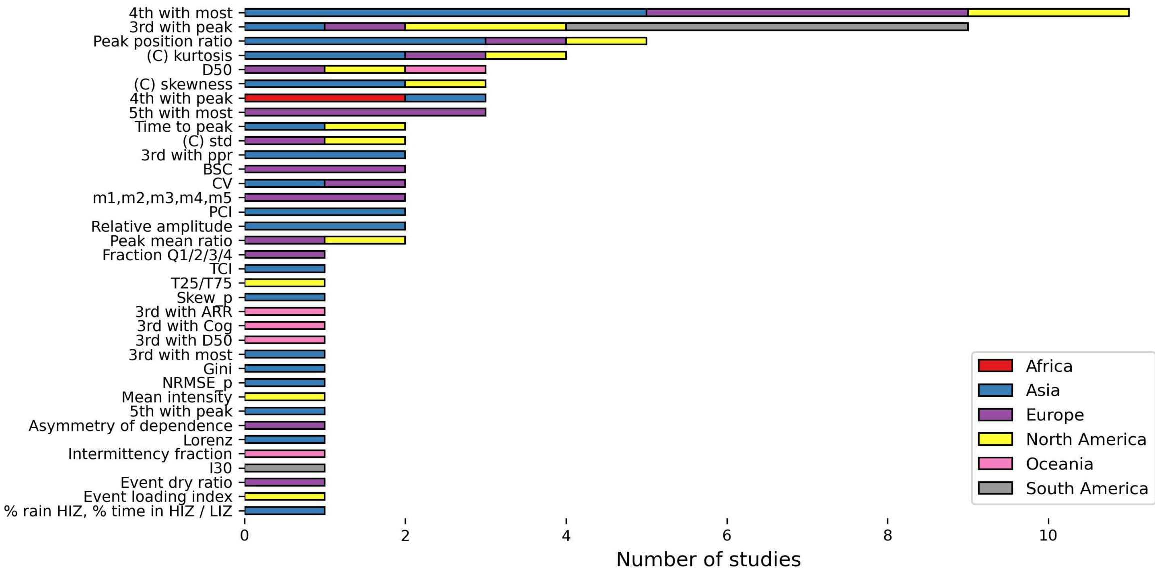

Figure S1. Distribution of metrics across the reviewed studies, showing both the number of studies in which each metric was applied and the countries from which these studies were drawn.

Table S2. Summary of studies by purpose, metric type, the type of rainfall events used in the study, and the processing stages applied. Note that some studies may be counted under more than one categorisation

Category	Subcategory	Detail	Number of studies
Study purpose	Characterise rainfall profiles in an area		23
	Impact of storm temporal profile on:	Flooding/hydrology	12
		Landslide	1
		Pollution	2
		Soil erosion	13
	Climatic study		6
	Stochastic event generation		3
	Evaluating satellite data		1
	Metric development		5
Metric type	Classification		35
	Continuous		28
Rainfall type	Real		49
	Synthetic		13
Rainfall processing	Raw rainfall events		26
	Dimensionless Mass Curves		28
	Unclear		7

S4 Silhouette score

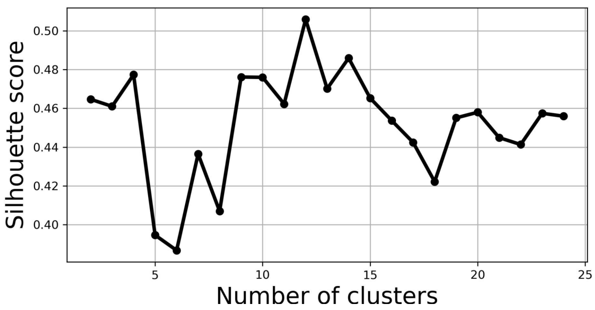

Figure S2. Silhouette scores for different numbers of clusters

S5 Repeat of experiments in Section 4.3 using double normalised events

Figures S3 and S4 present supplementary sensitivity analyses that isolate the contribution of de-dimensionalisation to the overall DMC sensitivity reported in Section 4.3, by evaluating sensitivity against double-normalised events that retain their original temporal resolution (i.e., without interpolation to 10 time steps).

For the majority of metrics, retaining the original temporal resolution substantially reduces sensitivity, with Spearman's ρ approaching 1 and sMAPE approaching zero. This confirms that interpolation to ten data points is the dominant driver of sensitivity to DMC construction for most metrics, and that double normalisation alone has limited effect on ranking or value distributions across events.

A notable exception is the cluster of metrics, including *maximum intensity*, *mean intensity*, *time to peak*, *standard deviation*, and *mean intensity within the HIZ*, which exhibit sMAPE values approaching 200. These metrics are defined in terms of absolute magnitudes, meaning that their values depend directly on the scale of the rainfall intensities. When applied to double normalised representations constrained to the range [0,1], this magnitude information is removed, and the resulting values are no longer directly comparable to those derived from the raw data. As a result, the difference between raw and normalised values is dominated by this scale mismatch, causing sMAPE to approach its upper bound. While variability is not eliminated under normalisation, it is substantially compressed relative to the raw values, which may span several orders of magnitude. This compression further inflates sMAPE, as differences are evaluated relative to a much smaller range. These results should therefore be interpreted as evidence of incompatibility between the metric definition and the normalised representation, rather than as an indication of genuine sensitivity.

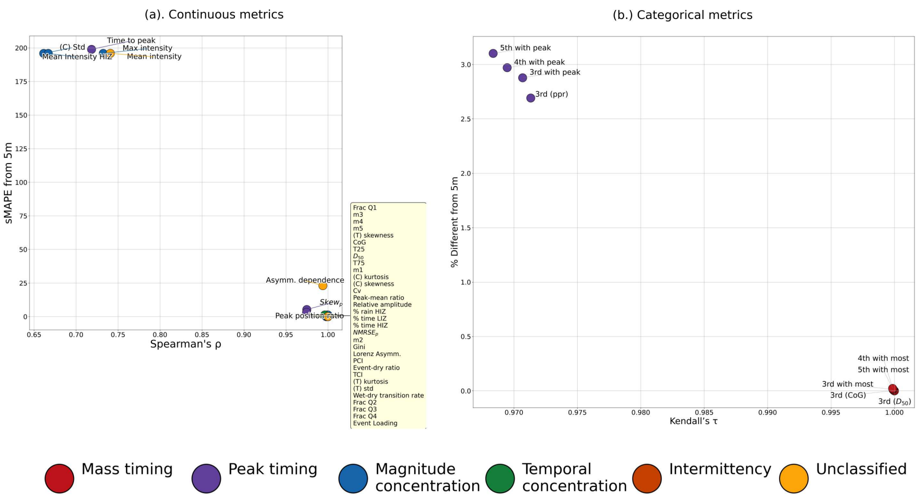

Figure S3. Sensitivity of metrics to calculation on double normalised events. For each metric, points represent comparisons between the metric calculated with 5-minute raw data and with a double normalised version of the event calculated on 5-minute data. For (a). continuous metrics the x-axis shows Spearman's rank correlation coefficient (p) and y-axis the symmetrical mean absolute percentage error (sMAPE). For (b). categorical metrics, the x-axis shows Kendall's tau and the y-axis the percent disagreement between the pairs of metric values.

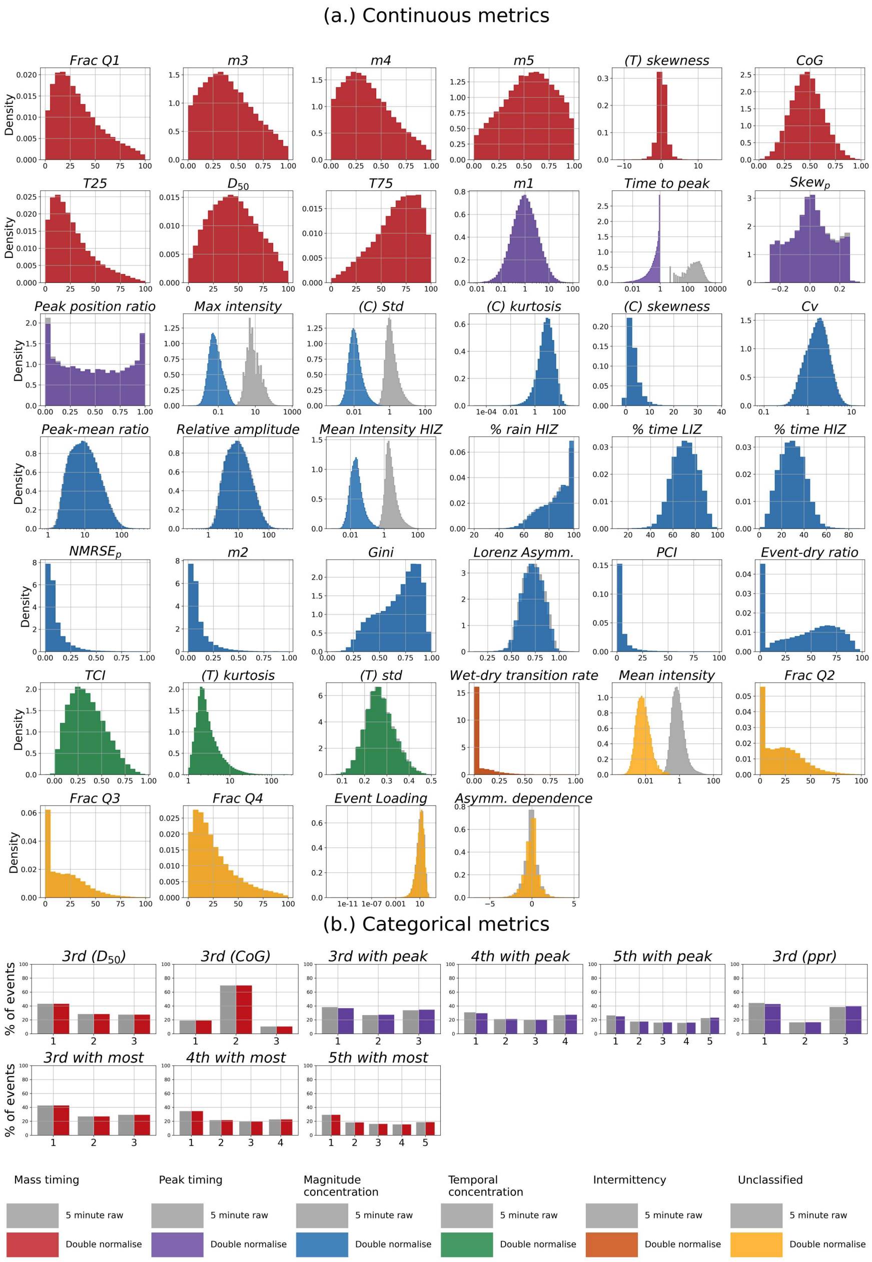

Figure S4. Sensitivity of metric distributions to calculation on double normalised events. Each subplot shows how the distribution of a given metric changes when calculated on raw rainfall data at 5-minute temporal resolution and on a double-normalised version of the event calculated on 5-minute data. For (a). continuous metrics, distributions are shown using overlaid histograms. For (b). categorical metrics, grouped bar charts show the relative frequency of each category across resolutions.

S6 Summary of experimental results for selected metrics

Table S3: Summary of experimental results for investigated metrics

Metric	Classification	Robust to: Temporal resolution	Robust to: DMC transformation
Frac. in Q1	Mass timing	×	×
m3 / m4 / m5	Mass timing	✓	✓
Temporal skewness [(T) skewness]	Mass timing	✓	✓
Centre of gravity (CoG)	Mass timing	✓	✓
T25 / T50 and D_{50} / T75	Mass timing	✓	✓
m1	Mass timing	×	×
3rd with D_{50}	Mass timing	✓	✓
3rd with CoG	Mass timing	✓	✓
3rd/4th/5th with most	Mass timing	✓	✓
Time to peak	Peak timing	×	×
$Skew_p$	Peak timing	×	×
Peak position ratio / Coefficient-peak-rainfall-intensity	Peak timing	×	×
3rd with ppr	Peak timing	×	×
3rd/4th/5th with peak	Peak timing	×	×
I30	Magnitude concentration	✓	×
Max intensity	Magnitude concentration	×	×
Classical standard deviation [(C) std]	Magnitude concentration	✓	×
Classical kurtosis [(C) kurtosis]	Magnitude concentration	×	×
Classical skewness [(C) skewness]	Magnitude concentration	×	×
Coefficient of vatriation	Magnitude concentration	✓	×
Peak-mean ratio / Rainfall intensity irregularity (n_i)	Magnitude concentration	×	×
Relative amplitude	Magnitude concentration	×	×
Mean intensity in HIZ	Magnitude concentration	✓	×
% rain in HIZ	Magnitude concentration	×	×
% time in LIZ / HIZ	Magnitude concentration	×	×
$NRMSE_p$	Magnitude concentration	×	×

Metric	Classification	Robust to:	
		Temporal resolution	DMC transformation
m2	Magnitude concentration	×	×
Gini coefficient	Magnitude concentration	✓	✓
Lorenz asymmetry coefficient	Magnitude concentration	×	×
Precipitation Concentration Index (PCI)	Magnitude concentration	×	×
Event dry ratio	Magnitude concentration	×	×
Temporal Concentration Index (TCI)	Temporal concentration	✓	✓
Temporal kurtosis [(T) kurtosis]	Temporal concentration	✓	✓
Temporal standard deviation [(T) std]	Temporal concentration	✓	✓
Wet-dry transition rate	Intermittency	×	×
Event loading index	Unclassified	×	×
Asymmetry of dependence	Unclassified	×	×
Mean intensity	Unclassified	✓	×
Frac. in Q2 / Q3 / Q4	Unclassified	×	×