Beyond Runoff Coefficient: Revealing Global Patterns of Process Connectivity in Runoff Generation through Intensity Integration (Major Revision)

This study investigates hydrological connectivity at the global scale using an index of runoff efficiency (RE), which combines the runoff coefficient (RC) and runoff intensity (RI). The authors identify distinct spatial patterns in RC, RI, and RE, including relatively high RC values in wet regions and high RI values in dry regions, and further suggest that these spatial variations are primarily controlled by climatic factors. The manuscript also shows that hydrological connectivity, as represented by RE, responds nonlinearly to precipitation intensity.

This is a very interesting idea, as it attempts to represent the complex hydrological concept of connectivity with a simple integrated index. However, I am not fully convinced by the way the manuscript links RE to the definition of connectivity, nor by the physical interpretation given to changes in RE. In particular, while RE may be a useful response-based metric, its relationship to hydrological connectivity as a broader process concept is not yet sufficiently justified. Given these concerns, I recommend that the manuscript be considered for publication only after the issues detailed in the comments below have been adequately addressed.

General comments

- In the review about concepts of hydrological connectivity, Bracken et. al. (2013, 10.1016/j.earscirev.2013.02.001) highlight the broad and multi-dimensional nature of hydrological connectivity. I agree that the authors aim to use the combination of RC and RI to represent the ratio and rate of the transfer process. However, RE cannot fully represent the broader concept of connectivity. For example, hydrological connectivity may also be defined in terms of spatial soil-moisture patterns or the connection state of subsurface flow systems, and these aspects cannot be captured by RE alone. I therefore recommend that the authors explore the introduction more on concepts of connectivity and better understand why RE can be one of the proxies for representing the connectivity. At present, the Introduction places too much emphasis on the limitations of RC studies.
- I do not fully understand the reason for including a hydrological model in the overall framework. The manuscript already derives quickflow through baseflow separation, which appears sufficient for the subsequent analyses. Although the authors state that the model is intended to represent interception and infiltration processes, these processes are not explicitly incorporated into the later analyses, nor are their effects quantified or discussed in a meaningful way.

  In addition, the event identification procedure does not seem to make use of the modeled rainfall–runoff relationship itself (e.g., the contribution of rainfall to the runoff in each step); instead, runoff events are first identified from the quickflow series and then matched to rainfall events based on timing. This makes the hydrological model useless in the framework, while introducing additional structural uncertainty.

  Furthermore, I think the model structure is not correct. In Formula 4, INF is proportional to SM. In other words, more wet soil leads to more infiltration. Is this correct?

  I therefore recommend that the authors either (1) use the quickflow estimated directly from baseflow separation and remove the model-based quickflow from the framework, or (2) improve the hydrological model and more fully justify the use of the model by explicitly identifying the events based on the model-derived rainfall–runoff process and

by quantifying how interception and infiltration influence the results.

- I do not agree with the way the authors link RE, connectivity, and flood risk in the manuscript. In particular, the term flood risk is not used precisely. Flood risk is generally understood as a function of hazard, exposure, and vulnerability, whereas RE cannot quantify all components of that relationship. Instead, I would suggest linking high RE to an increased likelihood of flood generation, rather than to flood risk itself.
- I agree with the authors that RE reflects a trade-off between RC and RI at the long-term timescale. However, this also highlights a potential limitation of RE as a representation of connectivity. For example, do two regions with the same RE value—one characterized by very high RI and very low RC, and the other by moderate values of both RI and RC—actually exhibit the same hydrological connectivity? If not, it remains unclear how RE can serve as a robust proxy for connectivity.
- I wonder how the authors manage the uneven distribution of data points across regions and climate zones. What is the influence of data availability on the analysis? Can it cause bias of the conclusion?

Specific comments:

- Line 32: Ombadi eta al. (2023) does not state any findings about melting rate and snowpack dynamics
- Line 41: I don't think RC is a common indicator to quantify the process connectivity. For example, Phillips, et al. (2011, 10.1002/hyp.8123) shows distinct definitions of connectivity and runoff coefficient, although they are correlated.
- Line 76: add hypotheses or research questions in the last paragraph.
- Line 200: the explanation of event-to-event variability analysis is not clear; Why the authors used 10 mm/day as a criterion, rather than other rainfall intensity values.
- Line 296: typo. Transformation ratio (i.e., runoff coefficient)
- Figure 4: I recommend including "slope" in the analysis. "Slope" has been widely recognized as an important factor in the concept of hydrological connectivity. In addition, I wonder why "area" was included in the random forest analysis, given that both RI and RC are already normalized by area.
- Figure 5: modify the y axis. Now this scale makes it hard to find the difference between the values
- Line 417: There is no clear connection between the sentences before and after "However." The high sensitivity of RE to rainfall intensity is expected because both RC and RI are sensitive to rainfall intensity, and RE is the product of these two variables. However, this does not resolve the issue with RE arising from the trade-off between RC and RI.

  In addition to the influence of rainfall intensity on RE, total rainfall depth may also affect connectivity or RE. It is recommended to discuss whether saturation-excess runoff in wet catchments could influence connectivity, as well.