Review: "GTDI: a gaming integrated drought index implying hazard causing and bearing impacts changing" by Zhao et al.

RC4: 'Comment on nhess-2024-45', Anonymous Referee #3

Many thanks for your positive feedback for the results and scientific significance in this study. We greatly appreciate the Reviewer's comments, all suggestions are helpful in improving this manuscript. We are committed to enhancing the quality of our manuscript based on the reviewers' comments. We have carefully studied, considered and responded to all comments point-by-point as follows. For clarity, all comments are given in black and responses are given in blue text.

Comment 1: GTDI: a spatially variable weight drought combining two single-type indices SSMI and SPEI for drought hazard causing and bearing impacts changing. Authors claim that GTDI has a greatly high correlation with single-type drought indices (SPEI and SSMI) which is obvious because both indices are used to develop GTDI.

Answer 1: Thank you for the positive feedback.We completely agree with the issue that you presented. It should be emphasized the primary advantage of GTDI is its ability to obtain a spatially variable weight distribution pattern between SPEI and SSMI. This allows the integrated drought index GTDI developed by SPEI and SSMI to give a composite state of basin or regional drought hazard causing and bearing conditions. Therefore, to be accurate, the GTDI is relevant and distinct from SPEI and SSMI.

Comment 2: This is not an individual validation of GTDI.

Answer 2: Thank you for your comment. As everyone is aware, the generation and impact mechanisms of drought are extremely complex, with far-reaching consequences (involving meteorology, hydrology, agricultrue, social economy, etc.).Thus, it is highly difficult to define an absolute "true value" for drought, resulting in a lack of a defined standard or process for evaluating the accuracy of drought indexes that reflect the full drought process. SPI, RDI, SMDI, DAI, and EVI are well-known drought indicators, however they only show a portion of the drought's impact. Although the GTDI developed in this manuscript, is described as a integrated drought index, its effectiveness can only be demonstrated by comparative analysis to. Considering the drought type represented by the GTDI and the data source used, SPEI, SSMI, and ETDI are empolyed to compare with GTDI in this study to illustrate GTDI's reasonableness and effectiveness .

Comment 3: Line 28: "GTDI exhibits the gaming feature" What are the features? The major question is how the author came up with this equation.

Answer 3: Thank you for pointing out this issue. The gaming feature of game theory is that it can try to find an optimal allocation method that maximizes the interests of each participant through mathematical analysis [24]. Any change in the participants will cause a corresponding change in the game situation, as we stated in lines 171 to 180.

As for the equation you mentioned, we only applied this method to the development of an integrated drought index based on the principles of game theory, and the original equation and the revelant description can be found in the listed references [24,25].

[24] Jato-Espino, D. and Ruiz-Puente, C.: Bringing Facilitated Industrial Symbiosis and Game Theory together to strengthen waste exchange in industrial parks, Sci. Total Environ., 771, 145400, https://doi.org/10.1016/j.scitotenv.2021.145400, 2021.

[25] Lai, C., Chen, X., Chen, X., Chen, X., Wang, Z., Wu, X., and Zhao, S.: A fuzzy comprehensive evaluation model for flood risk based on the combination weight of game theory, Nat. Hazards., 77, 1243-1259, https://doi.org/10.1007/s11069-015-1645-6, 2015.

Comment 4: Are there any sound criteria that support this form?

Answer 4: Thank you for your comment. Sorry, we are not sure which part of the manuscript you are referring to. After careful inspection, we think you should be referring to Table 2.

In response to your concerns, we will add a reference to Table 2 to explain the basis for the drought classification criterion we used. For example:

"*Table 2. Drought classification criteria for the SPEI, SSMI, GTDI and ETDI [26].*"

[26] Huang, F., Liu, L., Gao, J., Yin, Z., Zhang, Y., Jiang, Y., and Fang, W. (2023). Effects of extreme drought events on vegetation activity from the perspectives of meteorological and soil droughts in southwestern China. Science of The Total Environment, 903, 166562.

Comment 5: The soil moisture dataset resolution is very high for a very course and a very small catchment means all the regions could exhibit similar values how do authors distinguish?

Answer 5: Thank you for bringing up these issues. Sorry, we don't quite understand what you would like to express. After careful consideration, we conjecture that your concern is that the spatial resolution of the soil moisture dataset is "very low" rather than "very high." In response to your doubts, we would like to say that your concerns are indeed a difficult problem in our work. Because the accuracy of the soil moisture datasets currently available is indeed limited, we can only use relatively reliable datasets for this study. This could cause soil moisture in a very small catchment to exhibit a similar value. Once a soil moisture dataset with higher spatial resolution and reliable accuracy is released, we will consider using more detailed data for future studies.

Comment 6: What is the basis for classifying the GTDI? Line 194 "calculating approach of SSMI in this study is comparable to that of SPEI, while GTDI and ETDI are built on SSMI and SPEI" GTDI is using a weighted approach, and it may reflect different drought intensity/severity. Thus, the classification approach could not be straightforward.

Answer 6: Thank you for this comment. It should be explained that the classification of GTDI learns from the categorization of the meteorological drought index (SPEI). As indicated in our response to your comment 4, we will add a reference to explain this classification.

In fact, calculating GTDI using the game theory weight allocation method does not drastically affect drought intensity or severity, but it is a beneficial combination of SPEI and SSMI. Furthermore, our correlation research revealed that GTDI has a very strong association with single-type drought indices (SPEI and SSMI), indicating that there is reliable consistency between them. As a result, it appears more reasonable to apply a consistent drought categorization for them, whereas classification reasonability is difficult to verify if using another classification method for GTDI, which may even lead to greater confusion and inappropriateness.

Comment 7: How did authors build ETDI? Section 3.2 only shows the GTDI process.

Answer 7: Thank you for this comment. We apologize for the inadequate presentation of key methods.The detailed calculation process of the ETDI index will be stated in the supplementary material as suggested by Anonymous Referee #2.

Comment 8: Temporal evaluation of GTDI is needed to present along SPEI and SSMI.

Answer 8: Thank you for your positive feedback. In fact, we have put GTDI together with SPEI and SSMI for temporal evaluation and analysis, as presented in Figure 8. Figure 8 shows the comparison of drought identification trajectories of GTDI, SPEI, and SSMI over time, and based on this, we analyzed the differences and connections between the integrated drought index GTDI and the single drought indices SPEI and SSMI.

Comment 9: Figure 3: The results are not meaningful. What scale is used for calculating drought with GTDI? Is this drought tendency mild, moderate, or extreme?

Answer 9: Thank you for this comment. It should be explained that the monthly-GTDI is calculated based on SPEI-3 and SSMI-3.

We apologize for not fully understanding your concerns regarding the question, "*Is this drought tendency mild, moderate, or extreme?*".

The drought tendency in the Wei River Basin is aggravating, as we stated in lines 271 to 272 of the manuscript.

"*Therein, the linear tendency rate of GTDI is -0.024/10a, illustrating that the drought in the WRB is aggravating.*"

After careful consideration of your doubts, we speculate that you may would like to know the drought grade corresponding to the monthly GTDI index. Therefore, we have improved Figure 3 (a) as follows:

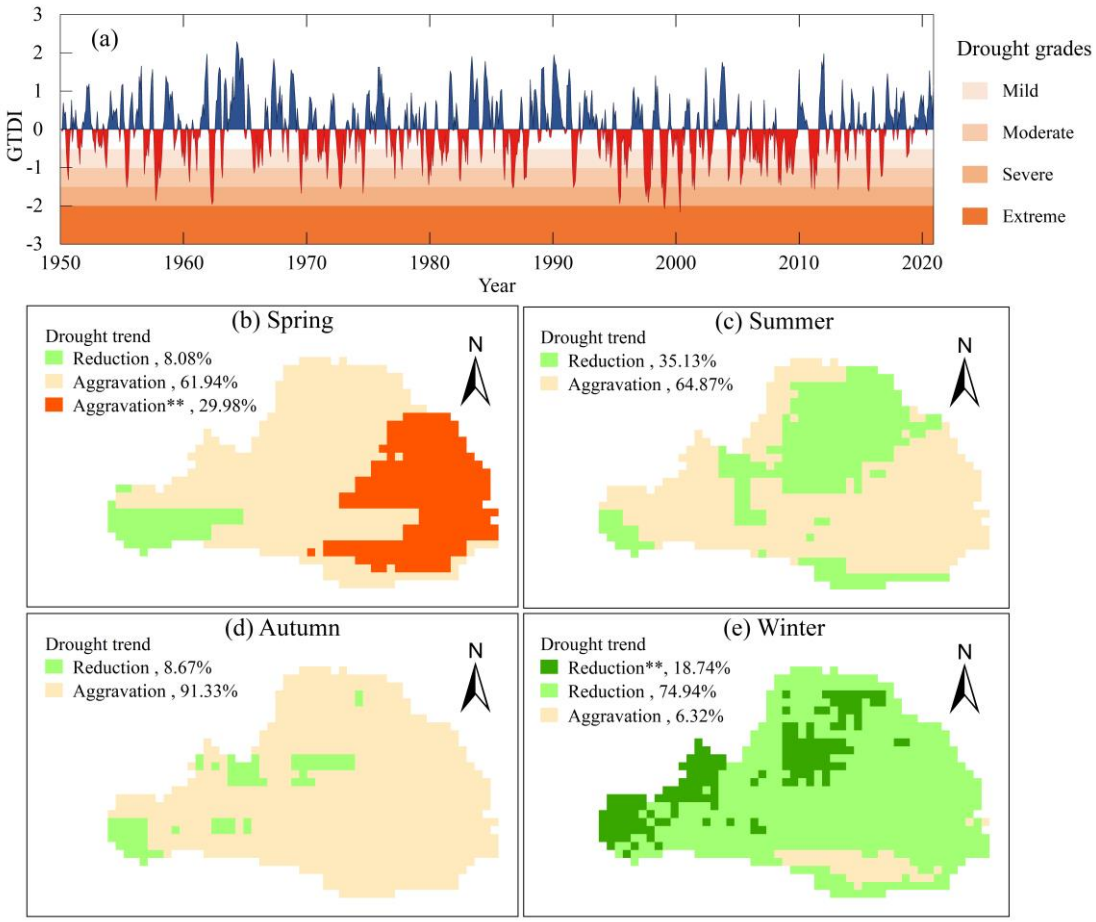

Figure 3. Temporal evolution characteristics of integrated drought in the Wei River Basin from 1950 to 2020 (a), and spatial distribution of drought trends in different seasons (b-e). The

symbol “**” donates the change is significant, and the percentage means the area proportion of different trend types.

Comment 10: GTDI is developed to present an agricultural drought. Right? Individual verification is needed.

Answer 10: Thank you for this comment. It is necessary to clarify that the GTDI isn’t developed to present an agricultural drought, it is an integrated drought index by combining two single-type indices: the meteorological drought index (SPEI) and the agricultural drought index (SSMI).

Comment 11: The efficacy verification in Table 6 only presents some percentage numbers. Why choose these specific months, which period? GTDI is overestimating the drought ratio because this river basin has a very small area where seasonal drought happens. Moreover, Fig. 6 and 7 present what is beyond my understanding. What is the purpose of showing satellite image?

Answer 11: Thank you for raising these issues. March to August was selected as the validation period in Table 6 because the surface vegetation during this period is more sensitive to changes in soil moisture. When drought occurs, vegetation growth will be restricted, and the LAI will be lower than the value of the drought-free month in the same period. Therefore, in this study, we used the change in the mean values of LAI in drought and non-drought months to verify whether the drought identified by GTDI, SPEI, SSMI, and ETDI is effective and reliable, that is, comparing the LAI mean values of drought and non-drought months identified by the drought index in the same month over many years. If the LAI mean values of drought months is lower than the LAI means value of non-drought months, it illustrates that the drought identified by the drought index is effective and reliable, as we stated in lines 207 to 237 of Section 3.4.2 of the manuscript.

The data listed in Table 6 are not the drought ratio for each month, but the efficacy ratio of drought index in identifying drought, as the name of the table suggests: “*Table 6. The efficacy ratios of four drought indices in different validation months*”

Figure 6 shows the spatial distribution of GTDI’s efficacy in identifying drought in the Wei River Basin, while Figure 7 shows the spatial distribution of SPEI, SSMI, and ETDI’s efficacy in identifying drought in the Wei River Basin, respectively. The legends "Fine" and "Poor" in the figures indicate the drought recognition performance of the drought index, that is, "Fine" means that the drought index accurately monitored the occurrence of drought, while "Poor" means that the drought index did not monitor the occurrence of drought, as we stated in line 237 of Section 3.4.2 of the manuscript.

The satellite image shown in Figure 6 is to illustrate the reason behind the poor and concentrated drought recognition performance of GTDI. As shown in Figure 6, the grid points with poor performance in June and August are concentrated in the forest area, which is the dark green area in the WRB's northeast hinterland. Forests have more access to deeper soil moisture than farming land and grassland [27,28], resulting in forests having higher drought tolerance than other terrestrial vegetation types [29,30]. The soil moisture data used in this study is only 0 to 10cm of soil surface layer, which could explain why GTDI's drought diagnosis ability in the forest region is skewed, as we stated in lines 365 to 372 of the manuscript.

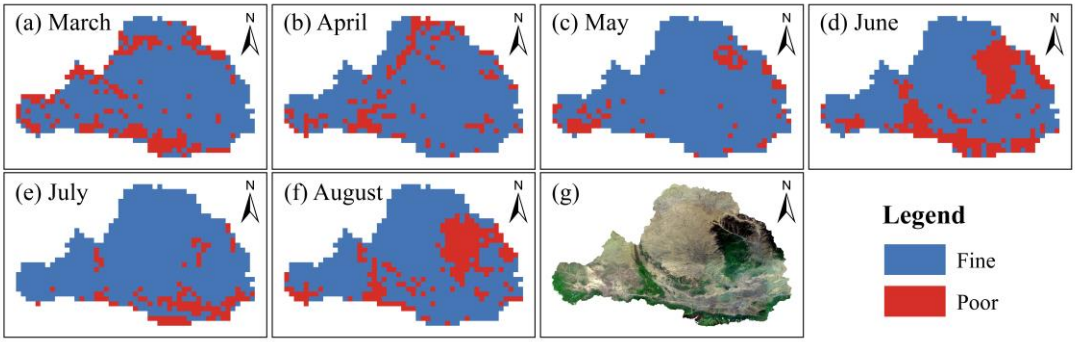

Figure 6. The spatial distribution of GTDI's efficacy in identifying drought in the Wei River Basin. Subfigures (a)-(f) depict the findings from March to August, and (g) displays a satellite image of the Wei River Basin.

[27] Xu, H., Wang, X., Zhao, C., and Yang, X. Diverse responses of vegetation growth to meteorological drought across climate zones and land biomes in northern China from 1981 to 2014, Agric. For. Meteorol., 262, 1-13, https://doi.org/10.1016/j.agrformet.2018.06.027, 2018.

[28] Bai, Y., Liu, M., Guo, Q., Wu, G., Wang, W., and Li, S. Diverse responses of gross primary production and leaf area index to drought on the Mongolian Plateau, Sci. Total Environ., 902, 166507, https://doi.org/10.1016/j.scitotenv.2023.166507, 2023.

[29] Jiang, W., Wang, L., Feng, L., Zhang, M., and Yao, R. Drought characteristics and its impact on changes in surface vegetation from 1981 to 2015 in the Yangtze River Basin, China, Int. J. Climatol., 40, 3380-3397, https://doi.org/10.1002/joc.6403, 2020.

[30] Chen, Q., Timmermans, J., Wen, W., and van Bodegom, P.M. A multi-metric assessment of drought vulnerability across different vegetation types using high resolution remote sensing, Sci. Total Environ., 832, 154970, https://doi.org/10.1016/j.scitotenv.2022.154970, 2022.

Comment 12: What do you mean fine, poor?

Answer 12: Thank you very much for your comment. The legends "Fine" and "Poor" in Figures 6 and 7 indicate the drought recognition performance of the drought index, that is, "Fine" means that the drought index accurately monitored the occurrence of drought, while "Poor" means that the drought index did not capture the occurrence of drought, as we stated in line 237 of Section 3.4.2 of the manuscript.

Comment 13: Fig. 9: it could be seen that drought is moderate in this basin, Thus authors are advised to expand the region for proper verification of GTDI.

Answer 13: Thank you very much for your comment. Figure 9 is used to compare the spatial evolution of SPEI, SSMI, and GTDI during the three drought events rather than describe the drought level in this basin. The three drought events we selected are to facilitate the comparison of the spatial evolution of droughts identified by SPEI, SSMI, and GTDI, as well as explore their connection and development discipline. Sorry, but we don't understand why you perceive the drought in the basin to be moderate and need to expand the area to properly verify GTDI. We are wondering if you would be willing to explain it in detail for us so that we can better understand and solve it. Among the three drought events shown in Figure 9, the 2000 drought event was clearly a severe drought event throughout the whole basin, because in May 2000, drought occurred in the entire Weihe River basin, and the average drought intensity was greater than 1, as listed in Table 7.

We sincerely appreciate your positive feedback and the valuable insights you have provided. Your comments and concerns have been duly noted, and we are committed to addressing each of them in the revised version of the manuscript.