General Comments:

The manuscript examines drought propagation while considering the impact of various meteorological factors and watershed characteristics. This study seeks to expand on existing knowledge of drought propagation by including the effects of a changing environment and watershed features. While many studies have focused on drought propagation using stationary drought indices, research like this, which applies non-stationary drought indices in the context of drought propagation, is increasingly important given the challenges posed by climate change. The manuscript is well-structured and clear, making it of interest to the readers of the NHESS Journal. However, I believe it could be significantly improved by addressing the points mentioned below.

Review Comments:

Major comments:

L94: As referring to few other articles, the details of area of basin are somewhat different as compared to the ones mentioned in this article. Also, the existing mountainous area and plain area details do not add up to total area of basin (refer article: https://doi.org/10.1016/j.oreoa.2024.100049.)

Response: Thank you very much for your review and valuable comments on our manuscript. According to your suggestion, the area of the Luanhe River Basin is 44,750 km^2, of which 43,940 km^2 are mountainous areas, as determined by searching authoritative information. The relevant content of the paper has been modified. The modifications are marked in red font. The details are as follows:

The area of the basin is about 44750 km^2, with an average width of 90km from east to west and a length of 500km from north to south, including a mountainous area of 43940 km^2.

L98: Could you kindly clarify whether it is possible for a basin to have an annual mean temperature in the range of 1 to 11°C, while the monthly mean temperature ranges from 17 to 25°C?

Response: Thank you very much for your review and valuable comments on our manuscript. Line 98 of the text should read: The annual mean temperature in the watershed ranges from 1 to 11°C, while the July mean temperature ranges from 17 to 25°C. The relevant text has been amended.

L119: How you have handled the grid points? Have you thought of considering the influence of the grids just on the boundary of the catchment?

Response: Thank you very much for your review and valuable comments on our manuscript. In this study, the downloaded grid point data were screened based on the watershed boundaries, and the grid point data whose grid center points were located within the watershed boundaries were selected as study data.

L176: Is there a specific reason why the Gamma distribution has been chosen for evaluating the Standardized Runoff Index (SRI)? While the Gamma distribution is commonly used for the Standardized Precipitation Index (SPI), the appropriate distribution for SRI can vary depending on the characteristics of the catchment. Are there any previous studies that support the use of the Gamma distribution for modelling runoff in this basin? If so, referencing these studies could help justify the decision to use the Gamma distribution. Try considering other distributions also, to improve the accuracy of the results when assessing drought severity and propagation.

Response: Thank you very much for your review and valuable comments on our manuscript. In this paper, before constructing the non-stationary drought index, the Weibull, Gamma, Log-normal, and Gumbel four distributions were selected to simulate the runoff. Evaluation of the simulation results based on the AIC, SBC, and GD metrics showed that the Gamma distribution performed optimally in the spring, summer, and autumn seasons, and also performed well in fitting the winter runoff series. Therefore, the Gamma distribution was used to calculate the SRI.

L194: You may consider mentioning that these meteorological variables are used as covariates in the evaluation of the non-stationary hydrological drought index. Additionally, could you include a justification for why large-scale climate factors were chosen as covariates in the evaluation of the nonstationary meteorological index, as well as the rationale for using meteorological variables in assessing the non-stationary hydrological index?

Response: Thank you very much for your review and valuable comments on our manuscript. The main purpose of this study is to investigate the influence of factors other than precipitation and runoff on drought propagation. Previous studies have shown that the large-scale climate index is an important factor influencing meteorological drought in the Luan River Basin, and that large-scale climate indices influence runoff indirectly by modulating atmospheric circulation and regional meteorological conditions, while meteorological factors (temperature, specific humidity, wind speed) influence runoff more directly through physical processes directly involved in the water cycle (e.g., precipitation, evaporation, snowmelt), as evidenced by the study of Das et al (2022). Therefore, in this study, large-scale climatic factors were selected as covariates to construct a non-stationary meteorological drought index, and meteorological variables were selected as covariates to construct a non-stationary hydrological drought index.

Das S, Das J and Umamahesh N V. Investigating the propagation of droughts under the influence of large-scale climate indices in India, Journal of Hydrology, 610, 127900. https://doi.org/10.1016/j.jhydrol.2022.127900, 2022.

L286: Table7: The AIC, SBC, and GD values for the all the different runoff models in the CDS region can be presented first, with the optimal model highlighted in bold, as done in the case of precipitation (Table 5).

Response: Thank you very much for your review and valuable comments on our manuscript. In this paper, the AIC, SBC and GD values of all runoff models were also calculated for the optimization of different runoff models. Due to excessive data, the AIC, SBC and GD values of all models were not listed in the table for the sake of making the article more concise. We present the results of all models in the table below:

Table1 AIC, SBC, and GD of the different models of runoff in the CDS region (the Bold indicates the optimal model)

	Spring			Summer			Autumn			Winter		
	AIC	SBC	GD	AIC	SBC	GD	AIC	SBC	GD	AIC	SBC	GD
Mod1	-63.96	-60.02	-67.96	139.83	143.77	135.83	-54.77	-50.83	-58.77	-422.75	-418.81	-426.75
Mod2	-63.66	-55.78	-71.66	137.69	245.57	129.69	-51.45	-43.57	-59.45	-420.46	-412.57	-428.46
Mod3	-69.83	-61.95	-77.83	142.67	150.55	134.67	**-57.83**	**-49.95**	**-65.83**	**-432.39**	**-424.51**	**-440.39**
Mod4	-62.04	-56.13	-68.04	**136.18**	**142.09**	**130.18**	-53.40	-47.49	-59.40	-421.02	-415.11	-427.02
Mod5	-63.53	-57.62	-69.53	141.62	147.53	135.62	52.81	-46.90	58.81	-427.48	-421.57	-433.48
Mod6	-65.04	-59.13	-71.04	140.72	146.63	134.72	-52.81	-46.90	-58.81	-421.99	-416.08	-427.99
Mod7	-65.44	-59.53	-71.44	141.20	147.11	135.20	-56.65	-50.74	-62.65	-420.79	-414.88	-426.79
Mod8	-62.02	-56.11	-68.02	139.86	145.77	133.86	-52.77	-46.86	-58.77	-420.86	-414.96	-426.86
Mod9	-61.81	-51.96	-71.81	138.55	148.40	128.55	-49.47	-39.61	-59.47	-418.46	-408.60	-428.46
Mod10	**-70.49**	**-60.64**	**-80.49**	144.33	154.19	134.33	-56.00	-46.15	-66.05	-432.10	-422.24	-442.10
Mod11	-62.91	-57.00	-68.91	141.60	147.51	135.60	-53.34	-47.43	-59.34	-422.49	-416.58	-428.49
Mod12	-66.27	-58.39	-74.27	142.80	150.68	134.80	-55.29	-47.41	-63.29	-420.55	-412.67	-428.55
Mod13	-62.03	-54.15	-70.03	143.45	151.33	135.45	-51.35	-43.47	-59.35	-425.67	-417.79	-433.67

Minor Comments:

L11: What do you mean by “The analysis of law of drought propagation”?

Response: Thank you very much for your review and valuable comments on our manuscript. Here 'analysis of law of drought propagation' specifically refers to revealing the influence of large-scale climate indices and meteorological factors on drought propagation by quantifying the probabilities and thresholds for the propagation of meteorological droughts into hydrological droughts in different seasons under both stationary and non- stationary conditions. The content here has been revised in response to another reviewer's comments, as follows:

Investigating the processes governing drought propagation under a changing environment is essential for advancing drought early warning and reducing socio-economic risks.

L23: Rephrase "Furthermore, watershed characteristics also be factors influencing spatial differences in drought propagation." Also, one-two lines about watershed characteristics can also be added in abstract if possible.

Response: Thank you very much for your review and valuable comments on our manuscript. Relevant contents have been revised based on expert comments and specific dimensions of watershed characteristics (geomorphology and vegetation) have been enumerated.

Furthermore, the spatial variability of drought propagation is further influenced by watershed characteristics, including the slope and leaf area index, which collectively alter runoff generation processes.

L58-L59: Rephrase ("Under the influence…complex and urgent.")

L84-L85: Rephrase ("Furthermore…characteristics"), grammatical mistake

L85-L89: Rephrase ("To assess…respectively"), sentence too long. Improving it will enhance readability

Response: Thank you very much for your review and valuable comments on our manuscript. The relevant contents of the paper have been checked and modified according to expert opinions, and the modified contents are marked in red font in the article as follows:

L58-L59: Under the influence of climate change and human activities, precipitation and runoff series show significant non-stationarity and uncertainty, and drought studies become more complex and urgent (Wang et al. 2015; Wang et al. 2020; Jehanzaib et al. 2023).

L84-L85: Furthermore, spatial and temporal differences in drought propagation are strongly related to watershed characteristics.

L85-L89: To evaluate the influence of external driving factors on drought propagation, NSPI and NSRI were constructed based on the GAMLSS framework with climate indices and meteorological factors as covariables. The propagation probability and propagation threshold of meteorological drought to hydrological drought were calculated by the Copula model under stationary and non-stationary conditions in different seasons, respectively.

L91: Section 2: more citations should be added in paragraph first, second and third (mainly line 94, 99, 109)

Response: Thank you very much for your review and valuable comments on our manuscript. Citations have been added to lines 94 and 99, respectively, in accordance with the expert's recommendations, while the content of line 109 has been deleted.

L128: The reference to the figure is incorrect. It should be: 'Figure 2 summarizes the steps of the current study.'

Response: Thank you very much for your review and valuable comments on our manuscript. The relevant contents of the paper have been checked and modified according to expert opinions, and the modified contents are marked in red font in the article as follows:

Fig.2 summarizes the steps of the current study.

L163: Here, α and β represent the shape and scale parameters, respectively, rather than the scale and shape parameters.

Response: Thank you very much for your review and valuable comments on our manuscript. The relevant contents of the paper have been checked and modified according to expert opinions. Modified as follows:

L163: In the formula, α and β are shape and scale parameters (α>0, β>0) and they are treated as constants in the GAMLSS framework.

L166: It can be mentioned that this approximate conversion is provided by Abramowitz and Irene (1965).

Response: Thank you very much for your review and valuable comments on our manuscript. Added on line 166 on the basis of the experts' suggestion, as follows:

The cumulative probability normalization method is based on the inverse normal function algorithm proposed by Abramowitz and Stegun (1965).

L190: As commented for L163, here, α and β represent the shape and scale parameters, respectively, rather than the scale and location parameter of the gamma distributions.

Response: Thank you very much for your review and valuable comments on our manuscript. The relevant contents of the paper have been checked and modified according to expert opinions, and the modified contents are marked in red font in the article as follows:

In the formula, α and β are shape and scale parameters (α >0, β >0) and they are treated as constants in the GAMLSS framework.

L256: The reference to the table is wrong. It should be: ‘Table 4’

L272: Typo error: Fig.4

Response: Thank you very much for your review and valuable comments on our manuscript. The relevant contents of the paper have been checked and modified according to expert opinions, and the modified contents are marked in red font in the article as follows:

L256: The AIC, SBC, and GD were used to select the optimal model, taking the CDS region as an example. The results of model preferences for the precipitation series are shown in Table 4.

L272: It can be seen from Fig.4 that the precipitation data values of the four seasons were basically within the 95% quantile interval, the deviation values in the worm chart were evenly distributed in the 95% confidence interval, and there was no obvious excess, which indicates that the residual fitting of the Gamma distribution meets the conditions.

L285: There can be other combinations of T, H, and W, such as W and H. Could you please include a statement explaining why only these specific model situations were considered?

Response: Thank you very much for your review and valuable comments on our manuscript. In this paper, 13 models are considered for calculating the optimal model for the runoff sequence, including the combination of T, H, and W, the combination of H and W, the combination of T and W, etc. The models mentioned in the paper are the optimal models for each region. To minimize redundancy, models other than the optimal model are not listed in Table 6.

L338: Could you elaborate on how and why an increase in temperature may be the primary factor contributing to the increased severity of hydrological droughts in the spring under non-stationary conditions, in contrast to stationary conditions?

Response: Thank you very much for your review and valuable comments on our manuscript. Based on the model simulation results, the optimal model for most of the regional runoff is Mod3 in Table6, with the covariates in Mod3 being temperature and humidity. According to the results in Table2, the temperature in the watershed shows a significant increasing trend in different seasons, while there is no significant trend in humidity. Therefore, the paper mentions that the increase in temperature is the main factor which leads to the increase in the severity of hydrologic drought in spring. In addition, the optimal model of runoff series from each area of the watershed for the different seasons was added to Section 4.2.2 of the article and is shown in Table 9. Then, changes were also made to Table 6 and Table 7 where relevant. The details are as follows:

Table 6 Different model situations considered for runoff simulation

Model	Parameter	
	α_t	β_t
Mod 1	~1	~1
Mod 2	~1	~ T and H
Mod 3	~ T and H	~1
Mod 4	~1	~ T
Mod 5	~ T	~1
Mod 6	~1	~ H
Mod 7	~ H	~1
Mod 8	~1	~W
Mod 9	~1	~ T, H and W
Mod 10	~ T, H and W	~1
Mod 11	~W	~1
Mod 12	~H and W	~1
Mod 13	~ T and W	~1

Table 7 AIC, SBC, and GD of the best suitable model of the non-stationary model of runoff in the CDS region

Season	The optimal model	
Spring	Mod 10	AIC: -70.28 SBC: -60.43 GD: -80.27
Summer	Mod 4	AIC:136.19 SBC:142.10 GD:130.19
Autumn	Mod 3	AIC: -58.67 SBC: -50.79 GD: -66.67
Winter	Mod 3	AIC: -4477 SBC: -439.89 GD: -455.77

The results of the optimal modeling of the non-stationary series for the 11 regional runoffs are presented in Table 9. Table 9 shows that there are some differences in the optimal models of the non-stationary runoff series in different regions in different seasons, among which the spatial differences of the optimal models in winter are the most significant. The optimal models in spring are mainly Mod3 and Mod10, in summer the optimal models are mainly Mod2, Mod4 and Mod8, in autumn the optimal models are Mod3 and Mod7, and in winter the optimal models are mainly Mod3 and Mod11.

Table 9 Optimal model of non-stationary runoff series in different seasons in each region of the basin

Region	Spring	Summer	Autumn	Winter
ZL	Mod3	Mod6	Mod7	Mod11
DL	Mod3	Mod2	Mod7	Mod11
GY	Mod3	Mod8	Mod7	Mod11

FN	Mod3	Mod2	Mod7	Mod12
WC	Mod3	Mod8	Mod7	Mod7
LH	Mod3	Mod4	Mod3	Mod3
LP	Mod3	Mod4	Mod3	Mod3
CDS	Mod10	Mod4	Mod3	Mod3
CDX	Mod3	Mod4	Mod3	Mod10
PQ	Mod10	Mod4	Mod3	Mod3
KC	Mod10	Mod4	Mod3	Mod3

L349: Rephrase for better clarity ("This…abundant"). Additionally, it would be helpful to mention the seasons varying with months in the study area section, providing readers with a better understanding of the different seasons in the Luanhe River Basin, China. It would also be beneficial to include some details about the general conditions of precipitation, temperature, and humidity across the various seasons.

Response: Thank you very much for your review and valuable comments on our manuscript. The percentage of precipitation at different seasons is detailed in the study area section of the article. The details are given below:

Affected by the continental monsoon climate, the basin has four distinct seasons of precipitation, with an average annual precipitation of 400~800mm, of which summer precipitation accounts for 67%-76% of the total annual precipitation; spring and autumn account for about 9% and 15% respectively; and winter precipitation accounts for only about 2% (Li et al. 2023).

L358-L360: Why might temperature (T) and humidity (H) be the primary climate-influencing factors in the upstream and downstream areas, in contrast to the midstream area? It may be helpful to include a brief explanation for a general audience to further clarify this.

Response: Thank you very much for your review and valuable comments on our manuscript. Table 9 added to the paper shows the optimal model for the series of unsteady runoff in different seasons in each region of the Luan River Basin. According to Table 9, the optimal model of runoff in ZL, DL, GY, FN, and WC regions is Mod7, and the optimal model of runoff in LH, LP, CDS, CDX, PQ, and KC regions is Mod3. Specific humidity is the main influencing factor in upstream region, and temperature and humidity are the main influencing factors in middle and downstream regions. According to the results in the table all the relevant contents in the text are modified as follows:

As can be seen from Table 9, specific humidity is the main influence on the differences in drought propagation in the upstream (ZL, DL, GY, FN, and WC), while drought in the middle and lower reaches (LH, LP, CDS, CDX, PQ, and KC) is influenced by a combination of temperature and specific humidity.

L406 and L408: The reference to the figure should be consistent throughout the article, using either 'Fig.' or 'Figure' in both instances.

Response: Thank you very much for your review and valuable comments on our manuscript. The figure is referenced throughout the article using “Fig.” for consistency. Relevant changes to the paper have been highlighted in red.