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Peer Review File

Non-linear relationships between air temperature and river water quality revealed by a panel dataset of 276 Chinese cities

Corresponding Author: Professor Zongwei Ma

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Version 0:

Decision Letter:

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Dear Professor Ma,

Your manuscript titled "Non-linear relationships between air temperature and river water quality revealed by a panel dataset of 276 Chinese Cities" has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Additionally, please provide methodological details to a level that can be understood and replicated by an independent researcher. Please highlight all changes in the manuscript text file.

Please submit your point-by-point responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
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We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Somaparna Ghosh, PhD
Associate Editor,

Communications Earth & Environment
Consulting Editor,
Communications Sustainability

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An updated and completed version of our Reporting Summary must be uploaded with the revised manuscript
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and also in our style and formatting guide Communications Earth & Environment formatting guide .

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Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The authors Liang et al. applied fixed effect panel regression models to estimate the effect of air temperature on water quality. The study focuses on city/prefecture level and different time scales, i.e. five-day, ten-day, fifteen-day, and monthly. Water quality data of DO, CODMn and NH3-N were obtained from the National Environmental Monitoring Centre of China and “merged” to the respective spatio-temporal scales.
Overall, the manuscript is well-written and provides insights on the impacts of air temperature on water quality and, in addition, assesses the quality-based water scarcity of a selection of cities. The conducted statistical analysis is scientifically

sound in identifying the marginal and total air temperature effects on water quality.
In my view, the potential use of these models should be examined carefully, and their limitations should be made clear. In my opinion, Figure 2 adequately demonstrates the effects of air temperature on water quality. I consider the other results and the conclusions drawn from them to be questionable. In this respect, the authors should reconsider the purpose of the study and adjust the focus of the assessment.
However, and this is my main criticism, I have some concerns with the analysis performed on the prefectural level and larger regions and the conclusions being drawn for these (large) regions and big river basins such as Yangtze and Yellow. What is the significance of a concentration over an area of several hundred or even million square kilometres, and how is this calculated?
The implications of the presentation of a concentration for the region must be considered. However, the data does not provide sufficient detail to ascertain the number of measurements taken at each station. It is important to note that upstream-downstream relationships are not considered in this analysis. The location of the pollutants discharged, and their respective sources must be determined. The underlying causes of water quality problems in urban areas do not necessarily originate within the city itself; they may in fact be situated outside the municipal boundaries. However, the way water managers can develop optimised strategies at the spatial level described to react to the changes caused by rising air temperatures remains unclear.
Another question that arises when assessing water scarcity is where the water for supplying the city is sourced and how much water is available for withdrawal. The question of whether surface water or groundwater is preferable is a complex one. Regarding surface water, it is necessary to establish whether the river is contaminated by pollutants, or whether the measurements of the water quality parameters relate to this section of the river.

Specific comments:
- The introduction section focusses on CODMn but does not account for DO and NH3-N
- Line 88: What is meant be risk-prone areas?
- Line 106: I think Li et al. (2024) are not properly cited here. Precipitation that directly enters the river to increase flow is very low.
- Line 196: How is the water availability of a city estimated?
- Line 380: The scarcity risk is 0.21 and not 0.12. Further, what does a scarcity risk of 0.21 mean?
- A conclusion should also be to mitigate pollution intakes.
- Fig. S2: Why is NH3-N not more strongly correlated to nitrogen fertilizer use? According to your analysis, NH3-N is slightly negatively correlated with sewage discharge and slightly positively correlated with nitrogen fertilizer use. Please explain, because both are sources contributing to NH3-N.
- Fig. S9: Please explain "salient samples".

Reviewer #2 (Remarks to the Author):

General Comment
The manuscript is well written and aligns closely with the scope of Communications Earth & Environment. It addresses an important and timely issue related to how climate variability affects river water quality and water availability. The key claims, including the non-linear inverted U-shaped relationship between air temperature and water quality indicators (DO, CODMn, NH_3-N), as well as the role of extreme temperature events in exacerbating organic pollution and contributing to quality-based water scarcity, are articulated. While related studies exist and are cited by the authors, the novelty of this work lies in the approach, the data used and the application across 276 cities.

Introduction
The introduction makes repeated use of the word “significant” in contexts where it may not refer to statistical significance (for example, in lines 34,35 and 41). In a manuscript based on quantitative analysis, this term should be used carefully and only when results are supported by statistical testing. To improve clarity and avoid confusion, I suggest replacing these instances with more precise alternatives such as “substantial,” “important,” or “notable,” unless the usage is directly tied to a statistical finding. This change will help maintain the rigour and accuracy of the manuscript's language.

Methodology
Line 109: DO was never defined; also, define it as it was done for the other water quality variables.
How did you integrate the different data scales? 0.25x0.25 grid, prefecture level and province level? Maybe add a few lines at the end of the data section.
The inclusion of more variables, such as discharge data (so not only precipitation), biological oxygen demand (BOD), could strengthen the interpretation of the observed relationships between temperature and water quality. If not possible to include, then discuss the possible implications of including them.
Quality-based water scarcity risk is a risk indicator, not a mode,l maybe it should be in a different section.

Results
The explanations for the observed inverted U-shaped relationship between air temperature and water quality indicators largely rely on interpretations drawn from previous studies. However, it is not demonstrated how the results of this study align with or differ from existing literature, particularly in similar geographic or climatic contexts. The manuscript would benefit from a more explicit comparison with prior findings in the same regions or from similar data environments.
Additionally, validation of the observed patterns through independent datasets or laboratory experiments simulating temperature effects on water quality parameters would help substantiate the proposed mechanisms and strengthen the

credibility of the conclusions.

Lines 228-230: “The inverted U-shaped non-linear effects on DO and CODMn are enhanced at longer time scales in all cases (Fig. 2a-d), while NH3-N is insignificant (Fig. 2e, f)." It is not clear from this figure how they overlap across time scales. The current colour scheme makes it challenging to distinguish between them, especially where the lines intersect. I recommend adjusting the figure to improve clarity. This could be done by increasing the transparency of the lines, using dashed or dotted line styles, or adding clearer labels or a legend that directly associates each curve with a specific time scale. This would help readers more easily interpret the patterns and support the statement in the text.

General comment on all figures: the captions should be understandable without the text; it would be nice to also add the explanation of abbreviations and units in the captions.

I appreciate the inclusion of regional and temporal heterogeneity analyses as well as the robustness checks, which enhance the overall credibility of the study. However, I recommend moving or summarising key numerical results from the Supplementary Information (e.g., Tables S2–S7) into the main manuscript. This would allow readers to more easily assess the strength of the findings without having to consult multiple appendices. Where feasible, the authors should also comment on what level of variation is considered acceptable (e.g., for R2) in fixed-effect panel studies of this kind to contextualise their findings.

Lines 335: The authors state, “We apply the daily maximum temperature above 35°C to explore the effects of extreme temperature,” but no rationale is provided for selecting this specific threshold. The manuscript would benefit from a justification for choosing 35°C as the cut-off for defining extreme heat for China.

Line 354: “8.63% and 9.51%, respectively”. Given the inherent uncertainties and variability in environmental panel studies of this scale, such precision may be misleading. I recommend rounding these figures to whole numbers (e.g., 9% and 10%) to reflect a more realistic level of accuracy. The same applies to other highly specific percentages throughout the manuscript.

Line 342: “High temperatures have little effect on DO and NH3-N, potentially because of the low levels of DO in the river” This would be a good opportunity to discuss the potential inclusion of other water quality parameters that may be more sensitive to extreme temperatures. Parameters such as biological oxygen demand (BOD), total nitrogen, total phosphorus, or chlorophyll-a might offer a more complete picture of temperature-induced water quality changes and could improve the explanatory power of the study.

I find the manuscript relevant and potentially suitable for publication, provided that the authors address moderate revisions to strengthen the validation and robustness of the findings.

Version 1:

Decision Letter:

** Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your coauthors **

Dear Professor Ma,

Your manuscript titled "Non-linear relationships between air temperature and river water quality revealed by a panel dataset of 276 Chinese Cities" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table".

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If you have any questions or concerns about any of our requests, please do not hesitate to contact me.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Somaparna Ghosh, PhD
Associate Editor,
Communications Earth & Environment
Consulting Editor,
Communications Sustainability

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

Dear authors,
you did a great job in improving the manuscript. You discussed all issues I raised and revised the text accordingly.

I am fine with the revised version and recommend to publish the manuscript as is.

Reviewer #2 (Remarks to the Author):

The authors have extensively integrated the reviewers’ feedback, and the revisions have substantially improved the clarity and quality of the manuscript. I am satisfied with the changes that have been made. I support its publication, pending a final check for minor typographical errors.

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Response to reviewers

Dear Editors and Reviewers:

Thank you very much for reviewing our manuscript and for the constructive comments, which greatly helped us to improve the manuscript. We sincerely appreciate the time and effort you and the reviewers have dedicated to our manuscript. These comments are valuable, helpful and important in revising and improving our paper. After carefully reading and considering all feedbacks and comments provided, we have amended our manuscript accordingly.

Point-by-point responses to these suggestions can be found on the following pages. The reviewers' comments are in black text, and our responses are in blue text. In the revised manuscript, we have highlighted changes in yellow. We also refer to the places which have been changed in response to each comment.

Reviewer #1 (Formal Review for Authors (shown to authors)):

General comments:

1. The authors Liang et al. applied fixed effect panel regression models to estimate the effect of air temperature on water quality. The study focuses on city/prefecture level and different time scales, i.e. five-day, ten-day, fifteen-day, and monthly. Water quality data of DO, COD_{Mn} and NH_3-N were obtained from the National Environmental Monitoring Centre of China and "merged" to the respective spatio-temporal scales.

Overall, the manuscript is well-written and provides insights on the impacts of air temperature on water quality and, in addition, assesses the quality-based water scarcity of a selection of cities. The conducted statistical analysis is scientifically sound in identifying the marginal and total air temperature effects on water quality.

Reply: Thank you very much for your constructive feedback and the time you dedicated to improving the quality of our manuscript. In response, we have provided additional justifications supported by previous research, incorporated supplementary mechanistic analyses such as spatial spillover analysis, and conducted site-level robustness test. These enhancements aim to further strengthen the credibility and reliability of our findings.

2. In my view, the potential use of these models should be examined carefully, and their limitations should be made clear. In my opinion, Figure 2 adequately demonstrates the effects of air temperature on water quality. I consider the other results and the conclusions drawn from them to be questionable. In this respect, the authors should reconsider the purpose of the study and adjust the focus of the assessment.

Reply: Thank you for your important feedback. The application of the fixed effects model, by incorporating fixed spatial (e.g., cities or provinces) and temporal effects (e.g., days, months, or years), mitigates the influence of unobservable factors such as geographical conditions and institutional environments. The demonstration of the importance of this empirical model has been provided by Maximilian Kotz's research (Kotz et al., 2022; Kotz et al., 2021), and we have also emphasised it: "*The models, including city and time (i.e., day, 5-day, 10-day, 15-day, and month) fixed effects, can be effectively applied to strengthen causal effects assessment by adjusting for* *unobserved unit-specific and time-specific confounders* [34,35]." (See Lines 139-142 in revised version, Page 9) Moreover, this approach has also been widely applied in previous research on water quality to assess the impacts of measures and policies. For example, Castillo-Castillo et al. (2025) applied the model at the municipality-year scale and found that improved resource allocation can enhance the effects of investment on water quality. Keeler et al. (2016) developed empirical models to predict NO_3^- contamination of water wells to estimate the social cost of nitrogen. In addition, other studies examined how policies such as estimating on how Conservation Reserve Programs (CRPs) and hydraulic fracturing affect environmental surface water quality (Keiser et al., 2019). These applications underscore the suitability of fixed effects models for exploring the relationships between meteorological factors and water quality conditions, consistent with the aims of our study.

However, the fixed effects model is constrained by the availability of control variable data and the ability to assess only simple response relationships. It may struggle to capture specific mechanisms and complex interactions of hydrological processes such as failure to incorporate groundwater dynamics and consideration of the spatial linkage between the monitoring stations and the water withdrawal locations. We have included a description of these limitations in **Section 4 Conclusion** to provide directions for improvement in future studies and added the sentence "*However, this study did not incorporate interactions between surface water and groundwater, the mediation effects among water quality indicators, or potential estimation biases arising from uncertain water withdrawal locations, which could be further examined in subsequent studies.*" (see Lines 450-453 in revised version, Page 25)

Regarding the reliability of the research findings and conclusions, Figure 2 primarily illustrates the overall average effects of air temperature on Chinese cities across multiple time scales. These effects may vary across regions, seasons, and under extreme temperature conditions (Kotz et al., 2021). Further heterogeneity analysis could contribute to elucidating the mechanisms of air temperature influencing water quality and identify temperature-sensitive risk hotspots. For instance, DO levels decline noticeably in summer and in eastern regions due to temperature-related effects (***Fig. 3 and 4*** in the manuscript), patterns also reported in previous studies (Zhang et al., 2025).

To further validate our results, we have found the observed inverted U-shaped response mechanism exhibited by temperature on water quality indicators in local river basins and laboratory experiments (Han and Bu, 2023; Jane et al., 2021; Li et al., 2024; Wang et al., 2016) and expanded the discussion of results. Specifically, we have revised the sentences "*Our findings reveal inverted U-shaped non-linear relationships between daily air temperature and concentrations of DO, COD_{Mn}, and NH_3-N (Table S2).*" (see Lines 215-217 in original version, Page 12) to "*Our findings reveal inverted U-shaped non-linear relationships between daily air temperature and concentrations of DO, COD_{Mn}, and NH_3-N (Table 1), consistent with previous regional lake dataset validation or experimental and observational studies* [16,17,43,44]*. Such consistency across different but related environmental contexts is probably because with rising temperatures, the decomposition of organic and inorganic substances initially lags behind the production, but eventually exceeds it* [45]." (see Lines 199-204 in revised version, Page 11)

3. However, and this is my main criticism, I have some concerns with the analysis performed on the prefectural level and larger regions and the conclusions being drawn for these (large) regions and big river basins such as Yangtze and Yellow. What is the significance of a concentration over an area of several hundred or even million square kilometres, and how is this calculated?

Reply: Thank you for your insightful comments and important questions. Our study adopts the city as the core spatial unit, with all data aggregation and statistical analysis conducted at this administrative level, reflecting the effectiveness of the city's overall water environment management. We fully understand the concern regarding the representativeness of city-level water quality conditions when conducting the research. Actually, the approach of aggregating water quality indicators to the municipal administrative scale is frequently applied in water quality assessments or large-scale empirical studies (Ministry of Ecological and Environment of the People's Republic of China, 2017; Sinha and Michalak, 2016).

For example, the Ministry of Ecology and Environment of the People's Republic of China evaluates city-level water quality conditions employing the arithmetic mean, guiding water management and policy decisions. Specifically, the method first calculates the average concentration of water quality indicators at all river monitoring sites in a city and then aggregates them into the overall water quality index. In the study by Sinha and Michalak (2016), they not only explored annual total nitrogen flux variations in hydrological units at the watershed scale, but also provided some high-level estimates aggregated at the continental scale by applying the mean value. They found that even at this highly aggregated scale, interannual variability was also substantial, driven largely by hydrological variability resulting from variations in total and extreme precipitation. As a result, the administrative area-based scales are prevalent to be employed in large-scale water quality studies, standards, etc. We have revised the sentence "*The water quality data are obtained from the National Environmental Monitoring Centre of China (http://www.cnemc.cn/sssj/) in the form of 4-hourly cross-sectional monitoring data and then combined at the same spatial and temporal scales as climate data.*" (see Lines 114-117 in original version, Page 7) to "*The water quality data is obtained from the National Environmental Monitoring Centre of China (http://www.cnemc.cn/sssj/) in the form of 4-hourly cross-sectional monitoring data and combined by applying the arithmetic mean from each monitoring station across the city* [32,33]*.*" (see Lines 114-117 in revised version, Page 7)

For river basin heterogeneity analysis, cities are classified into groups based on the located basins (e.g., the group of Yangtze River Basin cities, the group of Yellow River Basin cities), and city-level regression models are re-estimated for each group. This allows us to explore and capture the heterogeneity in temperature influences across different river basins.

Besides, to confirm robustness and reliability, we further conduct a robustness test at the monitoring-station level, and the coefficients of temperature remain consistent with the city-level models ***(Table R1, as Table S7 in revised SI)***. We have added the sentence "*Finally, we validate our main findings by downscaling the data to the monitoring section level, thereby confirming the model's applicability at a finer spatial scale (Table S7).*" (see Lines 343-345 in revised version, Page 20)

Table R1. Results of a robustness check when spatial scales are downscaled to monitoring sections.

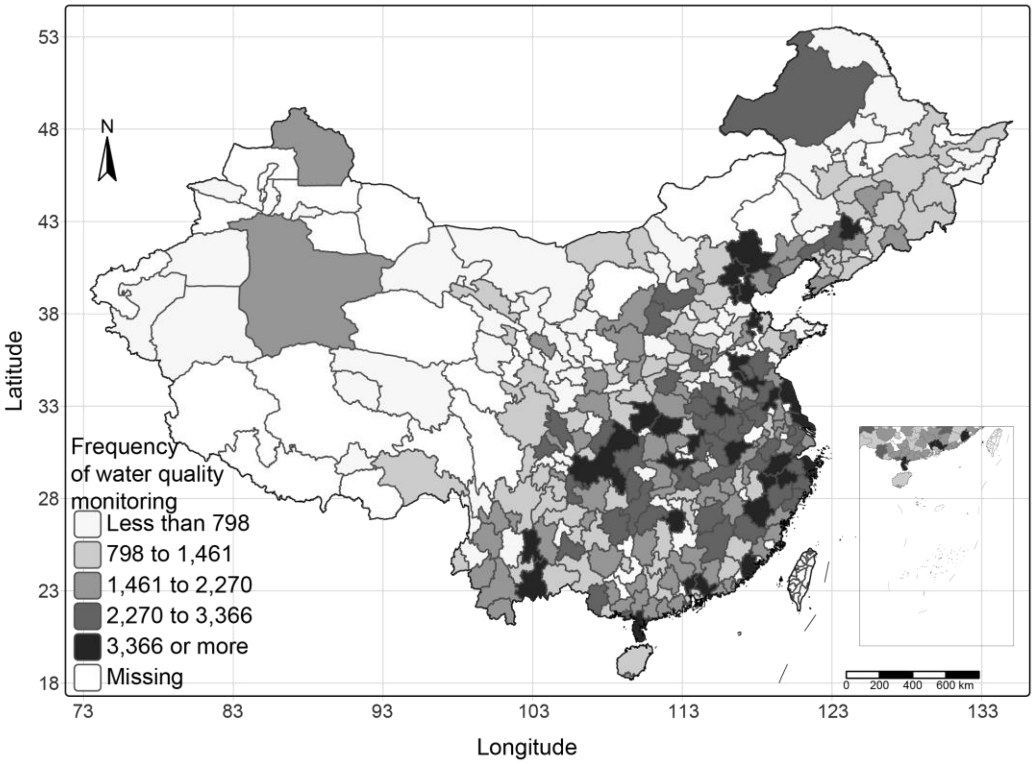
	(1) DO	(2) COD_{Mn}	(3) NH_3-N
Temp	-.0105***	.0000178	-.0133**
	(.0018)	(.0029)	(.0058)
Temp^2	-.000492***	-.00052***	-.00012
	(.000076)	(.00011)	(.0002)
Prec	-.577**	-.0679	1.11
	(.25)	(.52)	(.81)
GDP	.000115	-.00138**	.00105
	(.00014)	(.00063)	(.00075)
Industry	.161	.664	-1.63
	(.22)	(.72)	(1.2)
Emission	-.0144	.111*	-.0768
	(.022)	(.064)	(.1)
Temp×Prec	.0167	.00777	-.0276
	(.011)	(.022)	(.034)
N	9658	8412	8970
adj. R^2	0.532	0.761	0.640
BIC	-4556	4790	19492

4. The implications of the presentation of a concentration for the region must be considered. However, the data does not provide sufficient detail to ascertain the number of measurements taken at each station. It is important to note that upstream-downstream relationships are not considered in this analysis. The location of the pollutants discharged, and their respective sources must be determined. The underlying causes of water quality problems in urban areas do not necessarily originate within the city itself; they may in fact be situated outside the municipal boundaries. However, the way water managers can develop optimised strategies at the spatial level described to react to the changes caused by rising air temperatures remains unclear.

Reply: Thank you for your valuable feedback. The city-level water quality condition is derived by aggregating monitoring station data within each city using arithmetic means, following the method of ranking the environmental quality of surface water in cities and Sinha and Michalak (2016). Specific elaboration can be found in **Section Reviewer #1, General comments 2**.

We agree that information about the number of monitoring stations is necessary because it reflects both the priority given to water quality monitoring and the evolution of surface water management policies in China. To account for this, we have mapped the spatial distribution of the average total annual number of monitoring stations in each city ***(Fig. R1, as Fig. S3 in the revised SI)*** during the study period and added discussions in **Section Supplementary Text B**. The specific changes are as follows: "*The spatial distribution of surface water monitoring frequency in China shows a clear east–west gradient, with notable higher monitoring intensity in the eastern and central regions and relatively sparse monitoring in the western and northeastern areas. High-frequency monitoring is concentrated in densely populated and economically developed regions such as the Yangtze River Basin, the Pearl River Delta, the Yangtze River Delta, and the Beijing–Tianjin–Hebei area, reflecting greater water quality pressures and stronger monitoring capacity. In contrast, western and some northeastern regions exhibit lower monitoring intensity,, largely due to lower population density, weaker anthropogenic pressures, and higher monitoring costs.*" (see Lines 37-45 in revised version of SI, Page 2)

Fig. R1. Regional distribution of the annual frequency of water quality monitoring.



We also acknowledge that the underlying causes of water quality problems may not originate solely within city boundaries but can be influenced by upstream or neighboring regions. Therefore, we have complemented the analysis of spatial spillovers by adding spatial lag term variables of three water quality indicators based on our main models ***(Table R2, as Table S2 in the revised SI)***. The specific changes are as follows:

We have added a section ***Supplementary Text D: Spatial spillover effects of water quality indicators***: "*Given the high degree of interconnectedness in water ecosystems water pollution entails significant externalitiesand spatial spillover effects. To investigate the spatial lag effects of water quality indicators* $\sum_{j=1}^{n} Y_{ij} WQ_{j,t}$, *we employ spatial lag models outlined in Eqs. (S1 and S2). Here,* Y_{ij} *denotes the weight between locations i and j, representing the ith and jth component of the spatial weight matrix utilized to account for water quality impacts in neighbouring areas. The spatial weighting matrix is established using inverse distance weighting based on Euclidean distances.*" (see Lines 76-83 in revised version of SI, Page 3)

$$lag\_WQ_{j,t} = \sum_{j=1}^{n} Y_{ij} WQ_{j,t} \qquad (S1)$$

$$\begin{aligned} lnWQ_{i,t} = {} & \beta_0 ln\left(lag\_WQ_{j,t}\right) + \beta_1 \overline{Temp}_{i,t} + \beta_2 \overline{Temp}_{i,t}^2 + \beta_3 \overline{Temp}_{i,t} \\ & \times Prec_{i,t} + \eta_1 GDP_{i,t} + \eta_2 Industry_{i,t} + \eta_3 Emission_{i,t} \\ & + \eta_4 Prec_{i,t} + \alpha_i + \gamma_t + \varepsilon_{i,t} \end{aligned} \qquad (S2)$$

We have also added a discussion of the spatial spillover: "*Given the highly interconnected water ecosystems, pollutants are transported with flows, yielding spatial spillover effects. We add spatial lag terms for each water quality indicator based on the main model. Our results reveal that DO exhibits significant positive spatial spillover effects at different time scales, suggesting that elevated DO levels in neighbouring city rivers are associated with higher DO levels locally. There are no significant spatial spillover effects for* COD_{Mn} *and* NH_3*-N. The spatial dependence of DO might arise from similar hydroclimatic conditions (Fig. S1b), with similar levels of oxygen solubility in the water bodies and associated biological activities. Alternatively, it is possible that the transfer of other local pollutants (e.g., phosphorus, nitrate-nitrogen) reduces DO in neighboring cities. Furthermore, the spatial lag coefficients of DO decline over short-term scales 1 to 15 days and increase at the monthly scale, indicating that regional climate and activities reinforce spatial correlations over longer periods, which may need further research.*" (see Lines 84-96 in revised version of SI, Page 4)

Table R2. Panel regression results for the spatial spillover models.

	(1) DO 1 Day	(2) COD_{Mn} 1 Day	(3) NH_3-N 1 Day	(4) DO 5 Day	(5) COD_{Mn} 5 Day	(6) NH_3-N 5 Day	(7) DO 10 Day	(8) COD_{Mn} 10 Day
Temp	-.00218	-.000632	-.0138***	-.00563***	-.0046*	-.0162***	-.00774***	-.00759**
	(.0017)	(.0023)	(.0038)	(.0018)	(.0028)	(.0047)	(.0019)	(.003)
Temp^2	-.000197***	-.000198***	-.000308***	-.000342***	-.000293***	-.000409***	-.000448***	-.000353***
	(.000057)	(.00005)	(.00011)	(.000064)	(.000056)	(.00014)	(.000068)	(.000062)
GDP	-.000141*	.000105	.000364	-.000146*	.000126	.00048	-.000143*	.000169
	(.000073)	(.00034)	(.00057)	(.000075)	(.00037)	(.00067)	(.000077)	(.00037)
Industry	.3	.731	-.0991	.325	.71	-.268	.275	.64
	(.23)	(.77)	(.72)	(.23)	(.85)	(.81)	(.22)	(.83)
Emission	.0257	-.0569	-.0728	.0281	-.043	-.0845	.0303	-.0334
	(.018)	(.061)	(.13)	(.019)	(.066)	(.14)	(.021)	(.069)
Lag	.00123***			.000979***			.000702**	
DO	(.00033)			(.00034)			(.00033)	
Lag		-.00275			-.00286			-.00236
COD_{Mn}		(.0018)			(.0019)			(.0019)
Lag			.0124			.00929		
NH_3-N			(.011)			(.014)		
Prep	-3.93***	-1.58	-8.63***	-2***	-.169	-1.2	-1.39***	.574
	(1.1)	(1.8)	(2.8)	(.61)	(.98)	(1.6)	(.45)	(.7)
Temp ×	.11**	.0546	.391***	.052*	.0163	.0989	.0345*	-.0189
Prep	(.052)	(.078)	(.13)	(.028)	(.044)	(.069)	(.02)	(.032)
N	170752	118489	135182	36243	25557	29846	18790	13448
adj. R^2	0.439	0.594	0.475	0.466	0.602	0.461	0.476	0.606
BIC	53708	141627	314248	6370	30475	69079	2208	15818

Table R2. Continued.

	(9) NH3-N 10 Day	(10) DO 15 Day	(11) COD_{Mn} 15 Day	(12) NH3-N 15 Day	(13) DO Month	(14) COD_{Mn} Month	(15) NH3-N Month
Temp	-.0168***	-.00923***	-.0093***	-.0165***	-.0112***	-.0000278	.0156
	(.0055)	(.0019)	(.0032)	(.006)	(.0034)	(.01)	(.015)
Temp²	-.000493***	-.000517***	-.000418***	-.000536***	-.000586***	-.000503*	.0000223
	(.00017)	(.00007)	(.000077)	(.00019)	(.00012)	(.00026)	(.00045)
GDP	.000541	-.000139*	.000165	.000583	-.0000606	-.0048	.00618**
	(.00076)	(.000077)	(.00038)	(.00078)	(.00059)	(.007)	(.003)
Industry	-.401	.259	.663	-.475	1.09	.995	-14.2**
	(.89)	(.23)	(.85)	(.92)	(.82)	(4.5)	(5.9)
Emission	-.0843	.0304	-.0377	-.0851	-.265**	.18	.977***
	(.15)	(.02)	(.065)	(.15)	(.11)	(.15)	(.26)
Lag DO		.000542*			.00154*		
		(.00033)			(.00081)		
Lag COD_{Mn}			-.00191			-.000497	
			(.002)			(.0016)	
Lag NH3-N	.00382			.00667			.0523
	(.016)			(.018)			(.047)
Prep	-1.01	-1.25***	.268	-.0794	-1.62***	-.58	2.82
	(1.3)	(.38)	(.78)	(1.2)	(.56)	(2)	(2.6)
Temp × Prep	.0769	.0337**	-.00475	.0384	.0638***	.0439	-.0283
	(.057)	(.016)	(.033)	(.05)	(.024)	(.081)	(.11)
N	15860	12866	9312	11108	1849	1156	1313
adj. R^2	0.461	0.475	0.603	0.471	0.601	0.765	0.616
BIC	36905	1416	11006	26208	322	1106	3260

For water managers to develop optimisation strategies, our results provide a basis for identifying high-risk areas and designing region-specific interventions. By estimating the total effects of air temperature on water quality in each city, analysing spatial heterogeneity, and identifying water scarcity, we highlight critical regions where interventions are most needed. Corresponding strategies for these areas have been added to the conclusions section for clarity. We have revised the sentence "*Regions with poor water quality, as well as the Northeast and the Yangtze River Basin, are particularly susceptible to the adverse effects of normal temperatures. To mitigate these impacts and ensure the long-term sustainability of river ecosystems, it is imperative to enhance the efficiency of monitoring and governance. Cities such as Shangqiu, Huaibei and Wuhu should emphasize the contribution of temperature to the risk of quality-based water scarcity, and make timely adjustments to water withdrawals to guarantee the* *operation of production and life.*" (see Lines 405-412 in original version, Pages 21-22) to "*In southern China, rising temperatures have a more pronounced negative impact on DO. Regions with poor water quality, as well as the Northeast and the Yangtze River Basin, are particularly vulnerable to the adverse effects of normal temperature. To ensure the long-term sustainability of river ecosystems under rising temperatures, it is imperative to enhance the efficiency of water quality monitoring and governance through more effective pollutant control, adaptive water management, and risk mitigation strategies. Cities such as Shangqiu, Huaibei, and Wuhu should emphasize the contribution of temperature to the risk of quality-based water scarcity, and make timely adjustments to water withdrawals to guarantee the smooth operation of production and living conditions.*" (see Lines 438-448 in revised version, Page 25)

5. Another question that arises when assessing water scarcity is where the water for supplying the city is sourced and how much water is available for withdrawal. The question of whether surface water or groundwater is preferable is a complex one. Regarding surface water, it is necessary to establish whether the river is contaminated by pollutants, or whether the measurements of the water quality parameters relate to this section of the river.

Reply: Thank you for your insightful questions and feedback. We agree that it is crucial to consider the suitability of groundwater and surface water when withdrawing water. The exclusion of groundwater resources and their usage from the current dataset and scope is indeed a limitation of our study. However, the volume of water withdrawn from surface water is nearly 7 times larger than groundwater nationwide in 2020, making surface water the dominant source of water supply (Qian, 2021). Therefore, our attention to the temperature impacts on surface water quality and ultimately on city water use can provide valuable insights into the risks of city water use. For a city's water availability, we have carefully explained this in **Section Reviewer #1, Specific comments 4**.

However, the correspondence between the location of river monitoring and the location of water withdrawals is currently missing. This is because the applied water supply data are mainly categorised by city projects (e.g., water storage, drinking water, water lifting, and transferring projects), without precise withdrawal location. Nevertheless, our dataset matches the withdrawal data at the macro city level, which is sufficient for identifying the at-risk cities. We have also explicitly discussed these limitations: "*However, this study did not incorporate interactions between surface water and groundwater, the mediation effects among water quality indicators, or potential estimation biases arising from uncertain water withdrawal locations, which could be further examined in subsequent studies.*" (see Lines 450-453 in revised version, Page 25)

Specific comments:

1. The introduction section focuses on COD_{Mn} but does not account for DO and NH_3-N.

Reply: Thank you for your important feedback. We have expanded the introduction by discussing seasonal trends in these water quality indicators and integrating them with state policies. This revision provides a more balanced and comprehensive background, strengthening the foundation for the objectives and analyses. We have revised the sentence "*The rivers of China are dominated by oxygen-consuming pollution, i.e., permanganate index (COD_{Mn}) and ammonia nitrogen (NH_3-N), with significant differences in spatial distribution (Ma et al., 2020; Tang et al., 2022).*" (see Lines 69-71 in original version, Page 4) to "*The rivers of China are dominated by oxygen-consuming pollution, i.e., permanganate index (COD_{Mn}) and ammonia nitrogen (NH_3-N), and a series of corresponding discharge reduction targets have been established* [24]. *Despite the achievements of water quality improvement through water pollution control actions in China, the distribution of water quality varies across the country* [2]. *Furthermore, a seasonal trend in water quality is observed, with a notable decrease in dissolved oxygen (DO) and increases in COD_{Mn} and NH_3-N in most basins in summer* [2,25]." (see Lines 62-68 in revised version, Pages 3-4)

2. Line 88: What is meant be risk-prone areas?

Reply: Thank you for your question. We recognize that the term "risk-prone areas" in Line 88 may not have been clearly defined. "Risk-prone areas" is intended to describe cities or regional zones with elevated vulnerability to water quality degradation or water scarcity under climate change conditions. To improve the conceptual clarity, we have revised the sentence "*The research enables the identification of risk-prone areas of climate change impacts on water quality, providing sound understandings of optimal* *climate risks and water management policies.*" (see Lines 81-84 in original version, Page 4) to "*The research enables the identification of areas vulnerable to water quality degradation or notable water scarcity under the impacts of climate change, providing valuable insights into optimal climate risks and water management policies.*" (see Lines 79-81 in revised version, Page 4)

3. Line 106: I think Li et al. (2024) are not properly cited here. Precipitation that directly enters the river to increase flow is very low.

Reply: Thank you for your important feedback and highlighting the citation issue regarding Li et al. (2024) at Line 106. We agree that precipitation directly contributes to very low river runoff. Precipitation enters rivers primarily through surface runoff as well as infiltration through shallow soil and deeper groundwater aquifers, ultimately bringing contaminants to the water bodies. To ensure accuracy, we have revised the statement and updated the citation accordingly. Specifically, the original sentence "*We use precipitation as a control variable because of its direct or indirect effects, which can either enter the river directly to increase flow (Li et al., 2024), or form surface runoff to flush pollutants from cities, farmland into the water body (Zanon et al., 2020).*" (see Lines 99-101 in original version, Page 6) has been revised to "*We use precipitation as a control variable because it can form surface runoff, flushing pollutants from construction land and farmland into the water bodies* [28]." (see Lines 100-101 in revised version, Page 6)

4. Line 196: How is the water availability of a city estimated?

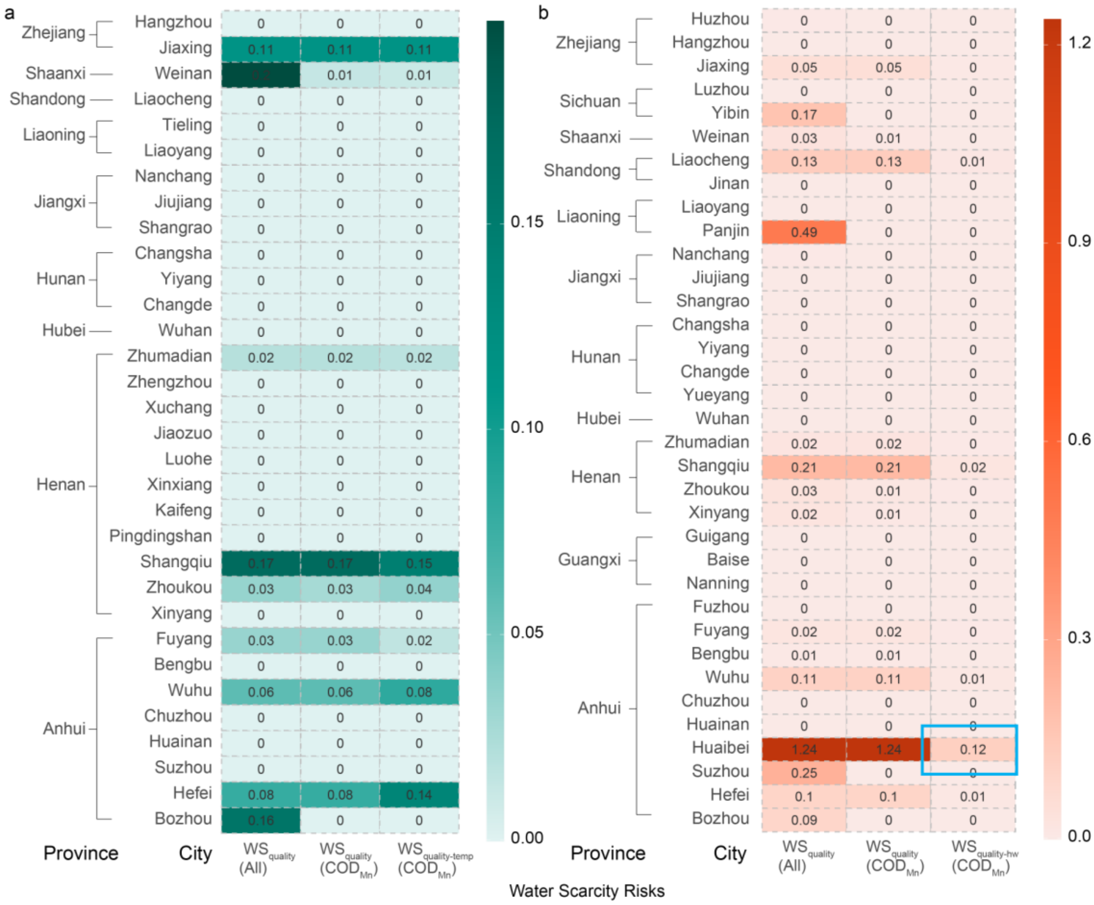
Reply: Thank you for your important question. We define the water availability of a city estimated is as its total water resources, i.e., the sum of surface runoff and precipitation infiltration recharge, consistent with previous studies (Li et al., 2022; Ma et al., 2020; van Vliet et al., 2017). Following Ma et al. (2020) and Li et al. (2022), who used provincial water resource totals from China Water Resources Bulletin as water availability, we extend this approach to the city level and collect the total water resources of each city.

Environmental flow requirements in previous definitions (Li et al., 2022; Ma et al., 2020; van Vliet et al., 2017) mainly account for 80% of total water resources, and $Q - EFR$ represents the city's available water withdrawals for human use. To avoid ambiguity, we have adjusted our description of variables: "*$WS_{quality}$ is quality-based water scarcity, and Q is the total water resources of city i, including surface runoff and precipitation infiltration recharge. EFR is the Environmental Flow Requirement, which is defined as 80% of the total water resources according to previous study [2]. The remaining 20% can be considered blue water available for human use without compromising the integrity of water-dependent ecosystems and livelihoods downstream. $Q - EFR$ represents the amount of available water withdrawals for a city.*" (see Lines 187-193 in revised version, Pages 10-11)

5. Line 380: The scarcity risk is 0.21 and not 0.12. Further, what does a scarcity risk of 0.21 mean?

Reply: Thank you for your careful reading and important question. We have rechecked the values in ***Fig. R2*** (third column, $WS_{quality-hw}$, *as* ***Fig.6*** in manuscript) and confirmed that the scarcity risk values for Huaibei is 0.12. A scarcity risk value quantifies the proportion of additional water withdrawals required when water quality degradation under extreme temperatures (elevated COD_{Mn} concentrations) renders part of the sectoral water supply inapplicable. For example, a value of 0.12 indicates that when heatwaves trigger elevated COD_{Mn} resulting in inapplicable sectoral water use scenarios, additional withdrawals account for 12 % of the city's available water withdrawals. To enhance the understanding of the indicator, we have revised the sentence: "*The heat wave scenario (four consecutive days above 35°C) is essentially similar to the high temperature scenario, with Huaibei exhibiting the most significant risk of water scarcity, followed by Shangqiu, which face additional water scarcity risk of 0.12 and 0.02, respectively (Fig. 6b).*" (see Lines 371-374 in original version, Pages 19-20) to "*The heat wave scenario (four consecutive days above 35°C) is essentially similar to the high temperature scenario, with the highest risk of water scarcity in Huaibei, followed by Shangqiu, which face water scarcity risk of 0.12 and 0.02 ($WS_{quality-hw}$), respectively (Fig. 6b). This means that the heatwave-driven elevation of COD_{Mn} requires the city to obtain additional 12% and 2% of available water withdrawals, respectively, to satisfy sector water demands.*" (see Lines 398-403 in revised version, Page 23)

Fig. R2 Water scarcity risks induced by water quality of city for high-temperature and heat wave of COD_{Mn} samples.



6. A conclusion should also be to mitigate pollution intakes.

Reply: Thank you for your valuable suggestion. In the revised manuscript, we have expanded **Section 4 Conclusion** to include recommendations for mitigating pollution inputs. We have revised the sentence *"To mitigate these impacts and ensure the long-term sustainability of river ecosystems, it is imperative to enhance the efficiency of monitoring and governance."* to "*To ensure the long-term sustainability of river ecosystems under rising temperatures, it is imperative to enhance the efficiency of water quality monitoring and governance through more effective pollutant control, adaptive water management, and risk mitigation strategies.*" (see Lines 441-444 in revised version, Page 23)

7. Fig. S2: Why is NH_3-N not more strongly correlated to nitrogen fertilizer use? According to your analysis, NH_3-N is slightly negatively correlated with sewage discharge and slightly positively correlated with nitrogen fertilizer use. Please explain, because both are sources contributing to NH_3-N.

Reply: Thank you for raising this important question. While both sewage discharge and fertilizer application are recognized sources of NH_3-N, their relationships with NH_3-N concentration are mediated by nitrogen transformation, transport processes, and regional management differences, weakening direct statistical correlations.

The weak positive correlation between NH_3-N and nitrogen fertilizer application can be attributed to the different migration behaviors of nitrogen species in soils. Compared with NH_3-N, nitrate nitrogen presents a stronger migration capacity at both the horizontal and vertical levels (Li et al., 2025). Therefore, fertilizer application tends to be more directly reflected in nitrate levels in surface waters, aligning with prior research indicating positive correlations between nitrate nitrogen and fertilizer application in surface water in China (Zhang et al., 2021). Moreover, pollutant transport from agricultural fields to rivers involves time lags and hydrological processes, making short-term correlations between NH_3-N and fertilizer application weak.

Interestingly, there is a negative relationship between NH_3-N concentration and sewage discharge. This seemingly counterintuitive pattern can be explained by regional disparities in socioeconomic development and wastewater management. Areas with larger sewage discharges typically are equipped with more treatment plants and are more economically developed, removing pollutants before being released into the environment ***(Fig. R3 b and c)***. Consequently, despite the high discharge volume, the efficient removal of nitrogenous pollutants during treatment and the greater assimilative capacity of receiving waters result in comparatively lower NH_3-N concentrations. In contrast, regions with lower sewage discharges are often less developed, with limited wastewater treatment infrastructure, leading to elevated NH_3-N levels even under relatively low discharge volumes***(Fig. R3 b and d)***.

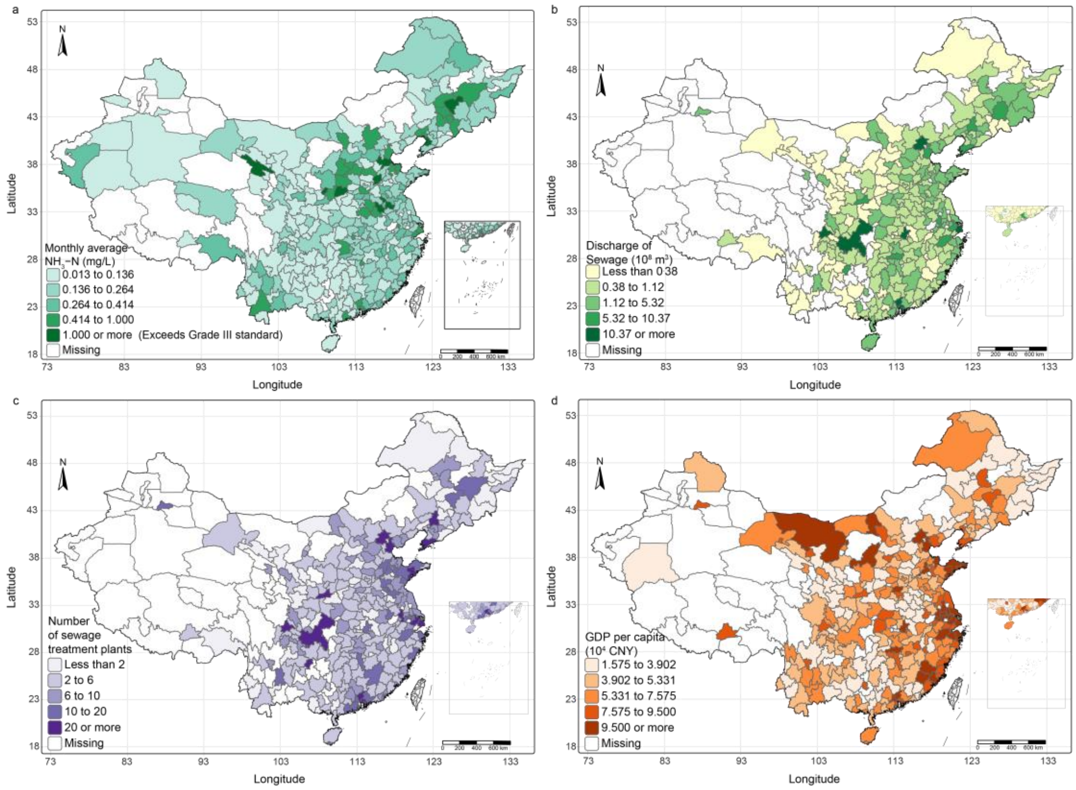


Fig. R3. Regional distribution of NH_3-N, sewage discharge, number of sewage treatment plants, and GDP per capita.

8.Fig. S9: Please explain "salient samples".

Reply: Thank you for your valuable comment. In our manuscript, "salient samples" represent city samples with relatively poor water quality, which are specifically screened to capture the characteristic patterns of temperature impacts in these areas. They are considered "salient" because they reveal distinctive and meaningful variations to elucidate the underlying impact mechanisms and identify potential risk hotspots. To improve clarity, we have added an explicit explanation of this term in the caption of Figure S9: "*Fig. S9. Marginal and total effects of temperature on COD_{Mn} and NH_3-N in Hai River as well as the middle and lower reaches of the Yellow River which has high water quality baselines (salient samples). (a) Marginal effects of temperature on COD_{Mn}. (b) Total effects of temperature on COD_{Mn}. (c) Marginal effects of temperature on NH_3-N. (d) Total effect of temperature on NH_3-N.*" (see Line 216 in revised version of SI, Page 18)

Reviewer #2 (Formal Review for Authors (shown to authors)):

General comments:

The manuscript is well written and aligns closely with the scope of Communications Earth & Environment. It addresses an important and timely issue related to how climate variability affects river water quality and water availability. The key claims, including the non-linear inverted U-shaped relationship between air temperature and water quality indicators (DO, COD_{Mn}, NH_3-N), as well as the role of extreme temperature events in exacerbating organic pollution and contributing to quality-based water scarcity, are articulated. While related studies exist and are cited by the authors, the novelty of this work lies in the approach, the data used and the application across 276 cities.

Reply: We sincerely appreciate the reviewer's positive comments about our work and efforts to improve the quality of our paper. In the following, we clarify/address the reviewer's comments point by point and indicate the revisions made in the revised manuscript accordingly.

Specific comments:

Introduction

The introduction makes repeated use of the word "significant" in contexts where it may not refer to statistical significance (for example, in lines 34,35 and 41). In a manuscript based on quantitative analysis, this term should be used carefully and only when results are supported by statistical testing. To improve clarity and avoid confusion, I suggest replacing these instances with more precise alternatives such as "substantial," "important," or "notable," unless the usage is directly tied to a statistical finding. This change will help maintain the rigour and accuracy of the manuscript's language.

Reply: Thank you for your important advice! Following your suggestion, we have carefully reviewed the entire manuscript to ensure that "significant" is used exclusively to denote statistical significance supported by quantitative testing. In all other instances, we have replaced it with more precise alternatives (e.g., "substantial," "notable," "prominent," or "critical," depending on the context). We believe this revision improves the clarity, rigour, and accuracy of the manuscript's language. The specific changes are as follows:

Original version	**Revised version**
The exacerbation of water scarcity can be attributed to water pollution (Li et al., 2022; Ma et al., 2020), which is a significant concern particularly in regions already facing water shortages (van Vliet et al., 2021). (see Lines 33-35 in original version, Page 2)	The exacerbation of water scarcity can be attributed to water pollution [1,2], which is a substantial concern particularly in regions already facing water shortages [3]. (see Lines 33-34 in revised version, Page 2)
The availability of clean water is a significant determinant of the health and well-being of residents, as well as a crucial factor in socioeconomic development (Krueger et al., 2019; McDonald et al., 2011). (see Lines 35-37 in original version, Pages 2-3)	The availability of clean water is a prominent determinant of the health and well-being of residents, as well as a crucial factor in socioeconomic development [4,5]. (see Lines 34-36 in revised version, Page 2)
Temperature plays a pivotal role in regulating river ecosystems dynamics (Miller and Hutchins, 2017), significantly influencing water quality through the sequential regulation of water temperature, evapotranspiration, the utility of runoff, and the physicochemical-biological responses (Van Vliet et al., 2023). (see Lines 40-43 in original version, Page 3)	Temperature plays a pivotal role in regulating river ecosystems dynamics [8], notably influencing water quality through the sequential regulation of water temperature, evapotranspiration, the utility of runoff, and the physicochemical-biological responses [9]. (see Lines 38-41 in revised version, Page 3)
Additionally, inadequate water quality can pose a significant constraint on water availability (Ma et al., 2020). (see Lines 128-130 in original version, Page 7)	Additionally, inadequate water quality can pose a critical constraint on water availability [2]. (see Lines 127-128 in revised version, Page 7)
The quality of water subjected to elevated temperatures for extended periods may undergo significant	The quality of water subjected to elevated temperatures for extended periods may undergo substantial

alterations from its typical patterns, potentially resulting in long-term deterioration (Hrdinka et al., 2015). (see Lines 333-335 in original version, Page 18)	alterations from its typical patterns, potentially resulting in long-term deterioration [65]. (see Lines 349-351 in original version, Pages 20-21)

Methodology

Line 109: DO was never defined; also, define it as it was done for the other water quality variables.

Reply: Thank you for your important advice for noticing this omission. We have defined DO as "dissolved oxygen (DO)" at its first occurrence, consistent with the definition style used for the other water quality variables. We have added the sentence "*Furthermore, a seasonal trend in water quality is observed, with a notable decrease in dissolved oxygen (DO) and increases in* COD_{Mn} *and* NH_3*-N in most basins in summer* [2,25]." (see Lines 66-68 in revised version, Page 4)

How did you integrate the different data scales? 0.25x0.25 grid, prefecture level and province level? Maybe add a few lines at the end of the data section.

Reply: Thank you for your valuable comments. All data were ultimately harmonized to the city-level, which serves as the spatial unit of analysis. For water quality data, following the method of ranking the environmental quality of surface water in cities and Sinha and Michalak (2016), we computed the arithmetic mean of all sites within a city to represent the city-level water quality. For gridded data (e.g. meteorological data), the city-level values are spatially aggregated based on prefecture-level city boundaries, taking the mean of all grids within each city. Economic variables (e.g., GDP, wastewater discharge) are collected at the prefecture-level city scale in China and require no further spatial processing.

The provincial-level data is collected at the province scale and analysed separately in the section of quality-based water scarcity, mainly for comparison with the city-level situation, and is not incorporated into the main city-level analyses in **Section 3 Results and discussion**.

We have added descriptions of the processing of spatial scales in the climate variables section as well as in the water quality data section, and the specific changes are as follows: "*The data are collected at 0.25° × 0.25° grid on daily scale, and are spatially merged according to the boundaries of municipalities to reflect the city temperature levels.*" (see Lines 94-96 in revised version, Page 6) and "*The water quality data is obtained from the National Environmental Monitoring Centre of China (http://www.cnemc.cn/sssj/) in the form of 4-hourly cross-sectional monitoring data and combined by applying the arithmetic mean from each monitoring station across the city* [32,33]." (see Lines 114-117 in revised version, Page 7)

The inclusion of more variables, such as discharge data (so not only precipitation), biological oxygen demand (BOD), could strengthen the interpretation of the observed relationships between temperature and water quality. If not possible to include, then discuss the possible implications of including them.

Reply: Thank you for your valuable suggestions. We agree that a series of variables such as discharge data, biological oxygen demand are important to the relationships between air temperature and water quality. As a result, our study applies fixed effects model to strengthen the causal inference of temperature effects on water quality (Kotz et al., 2021). Fixed effects in time allow us to account for contemporaneous national shocks to the climate and water quality, such as El Niño/Southern Oscillation (ENSO) events or the formulation of Action Plan for Prevention and Control of Water Pollution in 2015 (known as the 'Ten point Water Plan'). Regional fixed effects address the problem of omitted-variable bias in inter-regional comparisons, where unobserved, time-invariant differences are considered. Therefore, most measures affecting dependent variable (water quality) but not affecting independent variable (air temperature) have been controlled through region- and time-fixed effects.

Actually, the discharge data has already been included in our models as "emission", representing the city-level sewage discharge, which is the comprehensive measure available data currently. The BOD data has not yet started to be monitored in China on a large scale for surface water, so the data is missing. The absence of BOD and other variables poses certain limitations, as the estimated temperature impact struggles to distinguish direct effects as well as mediated indirectly through BOD, ultimately affecting water quality parameters of interest, such as NH_3-N. Nevertheless, within the scope of available data, this research has gathered as many relevant control variables as possible, while considering indicators incorporated in other literature (Keeler et al., 2016). Furthermore, multiple robustness tests and regional heterogeneity analyses have been employed to thoroughly investigate the validity and robustness of the temperature effects. We have also added a description of the relevant limitations: "*However, this study did not incorporate interactions between surface water and groundwater, the mediation effects among water quality indicators, or potential estimation biases arising from uncertain water withdrawal locations, which could be further examined in subsequent studies.*" (see Lines 450-453 in revised version, Page 25)

Quality-based water scarcity risk is a risk indicator, not a model, maybe it should be in a different section.

Reply: Thank you for your advice. In **Section 2.2 Methods** of this study, we agree with you that the quality-based water scarcity risk is a risk indicator rather than a model. To more accurately reflect its nature and align with the content of the methods section, we have revised the title of Section 2.2.3 to "Quality-based water scarcity risk calculation." (see Line 175 in revised version, Page 11)

Results

The explanations for the observed inverted U-shaped relationship between air temperature and water quality indicators largely rely on interpretations drawn from previous studies. However, it is not demonstrated how the results of this study align with or differ from existing literature, particularly in similar geographic or climatic contexts. The manuscript would benefit from a more explicit comparison with prior findings in the same regions or from similar data environments. Additionally, validation of the observed patterns through independent datasets or laboratory experiments simulating temperature effects on water quality parameters would help substantiate the proposed mechanisms and strengthen the credibility of the conclusions.

Reply: Thank you for your valuable feedback and important advice! We fully agree that explicit comparisons with prior studies and validation through independent evidence would improve the quality of the manuscript. Therefore, we have added some references reporting similar patterns of effects to enhance the persuasiveness of our findings ***(Table R3)*** and expanded the description: "*Our findings reveal inverted U-shaped non-linear relationships between daily air temperature and concentrations of*

DO, COD_{Mn}, and NH_3-N (Table 1), consistent with previous regional lake dataset validation or experimental and observational studies. [16,17,43,44] " (see Lines 199-202 in revised version, Page 11)

To improve the quality of our results discussion, we have further incorporated an analysis of the consistency in response patterns and the differences in temperature thresholds: "*Such consistency across different but related environmental contexts is probably because with rising temperatures, the decomposition of organic and inorganic substances initially lags behind the production, but eventually exceeds it* [45]*. Consequently, the marginal effects of temperature shift from positive to negative, leading the total effects to first increase and then decline (Fig. 2).* (see Lines 201-206 in revised version, Page 11) and "*However, the temperature thresholds in our study vary from previous work*[16,17,43,44]*, likely due to differences in hydrology, temperature ranges, and methodology.*" (see Lines 221-223 in revised version, Page 12)

Table R3. Previous research on the relationship between temperature and water quality indicators.

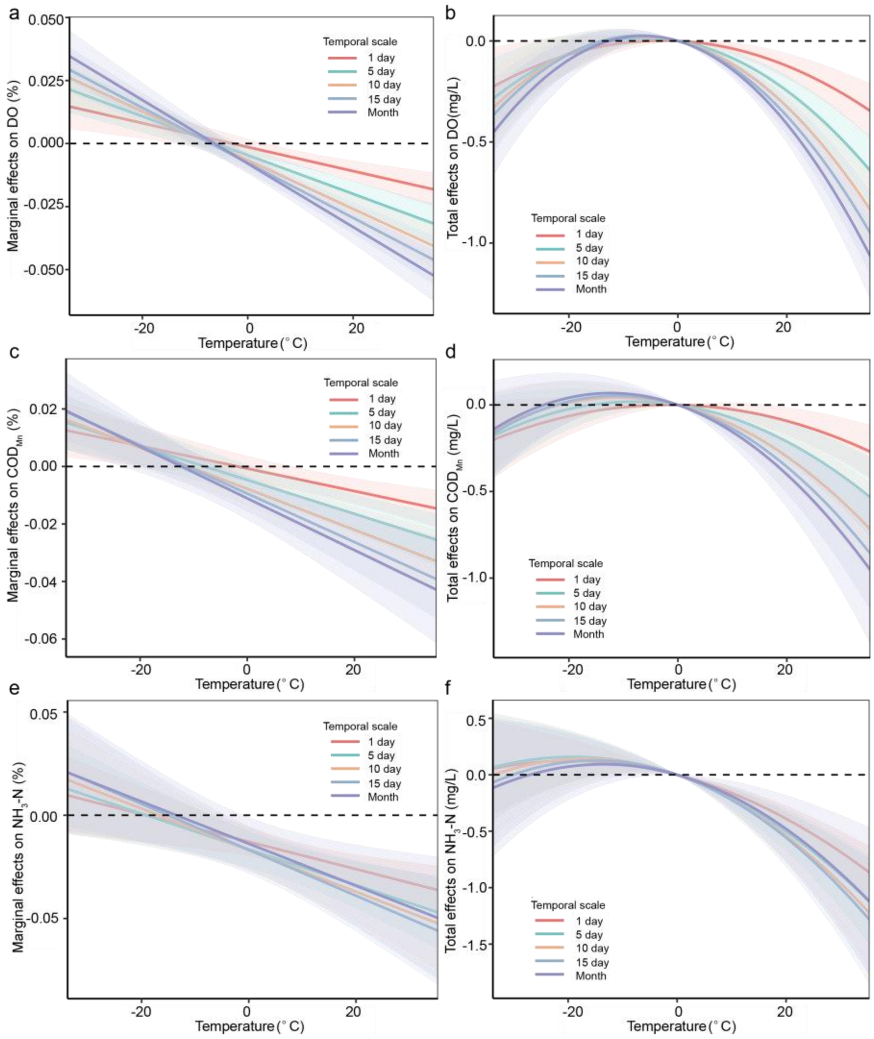
Previous research	Location	Description
Widespread deoxygenation of temperate lakes	Fig. 3b	The effect of temperature on DO exhibits an inverted U-shaped relationship.
The impact of climate change on the water quality of Baiyangdian Lake (China) in the past 30 years (1991–2020)	Fig. 4	The effect of temperature on COD is inverted U-shaped.
Screening of efficient ammonia–nitrogen degrading bacteria and its application in livestock wastewater	Section 3.3.2 and Fig. 2b	With an increase in temperature from 20 °C to 30 °C, the degradation rate of NH_3-N gradually rises, reaching 48.07% at 30 °C. However, when the temperature further increases from 30 °C to 40 °C, the degradation rate declines, with values of 36.68% at 35 °C and 32.88% at 40 °C.
Effects of temperature on aerobic denitrification in a bio-ceramsite reactor	Section 3.3 and Fig. 4	With an increase in temperature from 20 °C to 30 °C, the degradation rate of NH_3-N gradually rises, reaching 48.07% at

		30 °C. However, when the temperature further increases from 30 °C to 40 °C, the degradation rate declines, with values of 36.68% at 35 °C and 32.88% at 40 °C.

Lines 228-230: “The inverted U-shaped non-linear effects on DO and COD_{Mn} are enhanced at longer time scales in all cases (Fig. 2a-d), while NH_3-N is insignificant (Fig. 2e, f)." It is not clear from this figure how they overlap across time scales. The current colour scheme makes it challenging to distinguish between them, especially where the lines intersect. I recommend adjusting the figure to improve clarity. This could be done by increasing the transparency of the lines, using dashed or dotted line styles, or adding clearer labels or a legend that directly associates each curve with a specific time scale. This would help readers more easily interpret the patterns and support the statement in the text.

Reply: Thank you for your valuable suggestion! We have revised the figure by increasing the transparency of overlapping curves to reduce visual clutter for different time scales to enhance differentiation. These adjustments make it easier for readers to interpret the patterns across time scales and directly support the statement in Lines 228–230. The revised figure has been updated in the manuscript (see revised Figure 2).

Fig. R4 Marginal and total effects of temperature on water quality indicators at different time scales.



General comment on all figures: the captions should be understandable without the text; it would be nice to also add the explanation of abbreviations and units in the captions.

Reply: We appreciate the reviewer's valuable suggestion regarding figure captions. In the revised manuscript, we have carefully revised all figure captions to ensure that they are self-contained and understandable without needing to refer to the main text. The specific changes are as follows:

Original version	**Revised version**
Fig. 1 The workflow for (a) data preparation, (b) empirical model development, as well as (c) model results.	Fig. 1 Flowchart of the research strategies. (a) Data preparation, including data collection and spatial and temporal scales; (b) Epirical model development, including data model specification,

	model selection, heterogeneity analysis, robustness test, and spatial and temporal scales; (c) Model results, including normal temperature, extreme temperature, and water scarcity risks.
Fig. 2 Marginal and total effects of temperature on water quality indicators at different time scales. (a) Marginal and (b) total effects of temperature on DO; (c) Marginal and (d) total effects of temperature on COD_{Mn}; (e) Marginal and (f) total effects of temperature on NH_3-N.	Fig. 2 Marginal and total effects of temperature on water quality indicators at different time scales. (a) Marginal and (b) total effects of temperature on DO; (c) Marginal and (d) total effects of temperature on COD_{Mn}; (e) Marginal and (f) total effects of temperature on NH_3-N. The lines represent the nonlinear responses of three water quality indicators to temperature in the study region from 2014 to 2020, evaluated at different temporal scales (colors). The effects were estimated according to Eq. (1). The marginal effects first increase above zero and then decline, while the total effects exhibit an inverted U-shaped response. The shaded areas around the curves indicate the 90% confidence intervals of the estimated temperature effects, with standard errors clustered at the city level.
Fig. 3 Regional heterogeneity analysis of temperature impacts on water quality at 15-day scales. Estimates of the effects of the (a) linear and (b) quadratic terms of temperature when dividing the data according to geographic distribution. Estimates of the effects of the (c) linear	Fig. 3 Regional heterogeneity analysis of temperature impacts on water quality at 15-day scales. Estimates of the effects of the (a) linear and (b) quadratic terms of temperature when dividing the data according to geographic distribution. Estimates of the effects of the (c) linear

and (d) quadratic terms of temperature when dividing the data according to the Yangtze and Yellow Rivers.	and (d) quadratic terms of temperature when dividing the data according to the Yangtze and Yellow Rivers. The point estimates show the average effects of temperature under different groups, and the error bars represent the 90% confidence interval of the effect. The effects were estimated based on Eq. (1). The estimates reflect how water quality in each region responds to temperature according to the regional classification.
Fig. 4 Seasonal heterogeneity analysis of temperature impacts on water quality at 15-day scales. (a) Estimates of impacts by the temperature linear term and (b) quadratic term when dividing the data by season.	Fig. 4 Seasonal heterogeneity analysis of temperature impacts on water quality at 15-day scales. (a) Estimates of impacts by the temperature linear term and (b) quadratic term when dividing the data by season. The point estimates show the average effects of temperature under different groups, and the error bars represent the 90% confidence interval of the effect. The effects were estimated based on Eq. (1). The estimates reflect how water quality in each season responds to temperature according to the seasonal classification.
Fig. 5 Effects of single-day high temperature on COD_{Mn}. (a) Marginal and (b) total effects of single-day high temperature on COD_{Mn}.	Fig. 5 Effects of single-day high temperature on COD_{Mn}. (a) Marginal and (b) total effects of single-day high temperature on COD_{Mn}. The lines represent the nonlinear response of COD_{Mn} to temperature in the study area from 2014 to 2020. The effects were estimated based on Eq. (1). The marginal

	effect is initially negative and then becomes positive, while the total effect exhibits a U-shaped pattern. The starting and ending points of each curve correspond to the historical range of daily maximum temperatures above 35°C across all cities from 2014 to 2020. The shaded area around each curve represents the 90% confidence interval of the estimated temperature effect, with standard errors clustered by city. Full regression results are shown in Table S3.
Fig. 6 Water scarcity risks induced by water quality of city for high-temperature and heat wave of COD_{Mn} samples. (a) Risks for single-day high-temperature city samples. (b) Risks for heat wave city samples. WSquality (All) refers to quality-based water scarcity induced by COD_{Mn} and NH_3-N, and WSquality (COD_{Mn}) refers to quality-based water scarcity induced by COD_{Mn}. WSquality-temp (COD_{Mn}) represents the contribution of temperature to quality-based water scarcity induced by COD_{Mn}.	Fig. 6 Water scarcity risks induced by water quality of city for high-temperature and heat wave of COD_{Mn} samples. (a) Risks for single-day high-temperature city samples. (b) Risks for heat wave city samples. WSquality (All) refers to quality-based water scarcity induced by COD_{Mn} and NH_3-N, and WSquality (COD_{Mn}) refers to quality-based water scarcity induced by COD_{Mn}. WSquality-temp (COD_{Mn}) represents the contribution of temperature to quality-based water scarcity induced by COD_{Mn}. WSquality-hw (COD_{Mn}) represents the contribution of heatwave to quality-based water scarcity induced by COD_{Mn}. A scarcity risk value represents the proportion of additional water withdrawals required when water quality degradation under extreme temperature renders part of the sectoral water supply

	inapplicable.

I appreciate the inclusion of regional and temporal heterogeneity analyses as well as the robustness checks, which enhance the overall credibility of the study. However, I recommend moving or summarising key numerical results from the Supplementary Information (e.g., Tables S2–S7) into the main manuscript. This would allow readers to more easily assess the strength of the findings without having to consult multiple appendices. Where feasible, the authors should also comment on what level of variation is considered acceptable (e.g., for R^2) in fixed-effect panel studies of this kind to contextualise their findings.

Reply: We appreciate your recognition of regional and temporal heterogeneity analyses and robustness checks. To facilitate easier access for readers and provide a more straightforward assessment of our findings, we have moved key numerical results from the Supplementary Information ***Tables S2–S3*** into the main manuscript as ***Tables 1–2***.

Additionally, R^2 calculates the goodness of fit directly from the original dependent variable with the model predictors (with fixed effects terms), mixing between-group variation (cross-sectional variation) and within-group variation (time variation). The focus of our analysis is to capture the reasonable influence of temperature, so it is not our major concern whether we have fitted a sufficient number of variables to achieve the highest possible R^2 value. When the control variables are sufficient, avoiding multicollinearity issues among variables allows us to reflect the net effect of temperature despite the low R^2 value. On this basis, this study has incorporated as many variables as possible to achieve the capture of temperature effects, thus making it unnecessary to further consider the R^2 value. Moreover, the overall value fluctuates over a wide range across studies, ranging from nearly 0 to nearly 1 has been reported. For example, Kotz et al. (2022) applied the fixed effects model to estimate the effect of rainfall on economic, with the R^2 approximately 0.01, while Zhang et al. (2023b) has an R^2 of nearly 0.20 to explore relationships between household structure transitions and household carbon emissions. In this context, our results fall well within the acceptable R acceptable range reported in the literature.

Lines 335: The authors state, "We apply the daily maximum temperature above 35°C to explore the effects of extreme temperature," but no rationale is provided for selecting this specific threshold. The manuscript would benefit from a justification for choosing 35°C as the cut-off for defining extreme heat for China.

Reply: Thank you for your insightful advice. There are two key reasons for selecting 35°C as the high temperature threshold. The 'Monitoring indices of high temperature extreme' of China Meteorological Administration (CMA) clearly defines daily maximum temperature ≥35°C as meteorological hot weather, and accordingly issues high-temperature warning signals. In addition, this threshold has been widely used in empirical studies in the fields of high temperature and health, and energy load (Coppola et al., 2021; Farah et al., 2019). To enhance the persuasiveness of our threshold selection, we have added relevant references in the methodology section and revised the sentence "*We define single-day high temperature as the maximum temperature* $Temp_{Max35}$ *of city* i *exceeding 35°C on day* t *(Coppola et al., 2021; Farah et al., 2019).*" (see Lines 160-162 in original version, Page 9) to "*We define single-day high temperature as the maximum temperature* $Temp_{Max35}$ *of city* i *exceeding 35°C on day* t*, and this threshold has been adopted widely in previous studies* [37-39]." (see Lines 159-161 in revised version, Page 9)

Line 354: "8.63% and 9.51%, respectively". Given the inherent uncertainties and variability in environmental panel studies of this scale, such precision may be misleading. I recommend rounding these figures to whole numbers (e.g., 9% and 10%) to reflect a more realistic level of accuracy. The same applies to other highly specific percentages throughout the manuscript.

Reply: Thank you for your important suggestion. We agree that given the inherent uncertainties in large-scale environmental panel studies, reporting overly precise percentages may be misleading. Accordingly, we have rounded such figures to whole numbers throughout the revised manuscript to better reflect the realistic accuracy of the data. The specific changes are as follows:

Original version	**Revised version**
Our results demonstrate both single-day high temperatures (>36.6°C) and	Our results demonstrate both single-day high temperatures (>37°C) and

heatwaves (four consecutive days above 35°C) significantly increase river permanganate index (COD_{Mn}) concentrations, worsening organic compounds pollution. (see Lines 21-24 in original version, Page 2)	heatwaves (four consecutive days above 35°C) significantly increase river permanganate index (COD_{Mn}) concentrations, worsening organic compounds pollution. (see Lines 21-24 in revised version, Page 2)
Additionally, these extreme temperature events contribute over 66.7% and 9.51% to quality-based water scarcity, which presents considerable challenges to water withdrawals in cities. (see Lines 24-26 in original version, Page 2)	Additionally, these extreme temperature events contribute over 67% and 10% to quality-based water scarcity, which presents considerable challenges to water withdrawals in cities. (see Lines 24-26 in revised version, Page 2)
Specifically, the inflection points for the effects of temperature on DO, COD_{Mn}, and NH_3-N exhibit certain variations, being -3.71°C, -1.81°C, and -21.23°C, respectively (Fig. 2a, c, e). (see Lines 207-209 in original version, Page 11)	Specifically, the inflection points for the effects of temperature on DO, COD_{Mn}, and NH_3-N exhibit certain variations, being -4°C, -3°C, and -21°C, respectively (Fig. 2a, c, e). (see Lines 206-208 in revised version, Page 11)
Interestingly, the total effect is negative while the marginal is positive for DO and COD_{Mn} at below -7.42°C and -3.62°C (Fig. 2b, d), respectively. (see Lines 220-200 in original version, Page 12)	Interestingly, the total effect is negative while the marginal is positive for DO and COD_{Mn} at below -7°C and -4°C (Fig. 2b, d), respectively. (see Lines 218-219 in revised version, Page 12)
It is notable that the response of COD_{Mn} shifts to a positive U-shape and subsequently increases above 36.6°C, suggesting high temperatures can contribute to the deterioration of water quality. (see Lines 336-339 in original version, Page 18)	It is notable that the response of COD_{Mn} shifts to a positive U-shape and subsequently increases above 37°C, suggesting high temperatures can contribute to the deterioration of water quality. (see Lines 352-354 in original version, Page 21)
When exceeding 35°C for two and four consecutive days, the concentration of COD_{Mn} increases by 8.63% and 9.51%,	When exceeding 35°C for two and four consecutive days, the concentration of COD_{Mn} increases by 9% and 10%,

respectively. (see Lines 353-354 in original version, Page 19)	respectively. (see Lines 374-375 in revised version, Page 22)
For single-day high temperatures, cities such as Jiaxing, Zhumadian, Shangqiu, Zhoukou, Fuyang, Hefei, and Wuhu are exposed to COD_{Mn}-induced quality-based water scarcity risks, with the contribution of temperature exceeding 66.7% (i.e., the contribution of temperature to COD_{Mn}-induced risk (Eq. (6)) divided by total COD_{Mn}-induced risk (Eq. (5))) (Fig. 6a). (see Lines 367-371 in original version, Page 19)	For single-day high temperatures, cities such as Jiaxing, Zhumadian, Shangqiu, Zhoukou, Fuyang, Hefei, and Wuhu are exposed to COD_{Mn}-induced quality-based water scarcity risks, with the contribution of temperature exceeding 67% (i.e., the contribution of temperature to COD_{Mn}-induced risk (Eq. (6)) divided by total COD_{Mn}-induced risk (Eq. (5)) (Fig. 6a). (see Lines 394-398 in revised version, Pages 22-23)
Secondly, temperatures above 36.6℃ for a single day and heatwaves exceeding 35 ℃ two and four consecutive days of can significantly elevate COD_{Mn} concentrations in rivers. (see Lines 398-400 in original version, Page 21)	Secondly, temperatures above 36.6 ℃ for a single day and heatwaves exceeding 35 ℃ two and four consecutive days of can significantly elevate COD_{Mn} concentrations in rivers. (see Lines 431-433 in revised version, Page 24)
Finally, an increase in COD_{Mn} induced by single-day high temperature and heatwaves contribute to the quality-based water scarcity related to CODMn at a high level, with above 66.7% and 9.51%, respectively. (see Lines 400-403 in original version, Page 21)	Finally, an increase in COD_{Mn} induced by single-day high temperature and heatwaves contribute to the quality-based water scarcity related to COD_{Mn} at a high level, with above 67% and 10%, respectively. (see Lines 433-436 in revised version, Page 24)

Line 342: “High temperatures have little effect on DO and NH_3-N, potentially because of the low levels of DO in the river” This would be a good opportunity to discuss the potential inclusion of other water quality parameters that may be more

sensitive to extreme temperatures. Parameters such as biological oxygen demand (BOD), total nitrogen, total phosphorus, or chlorophyll-a might offer a more complete picture of temperature-induced water quality changes and could improve the explanatory power of the study.

Reply: Thank you for this constructive suggestion. We acknowledge that incorporating additional parameters such as biological oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), and chlorophyll-a could indeed provide a more comprehensive understanding of temperature-induced changes in river water quality. However, the lack of long-term regular national monitoring data is not feasible to include these indicators and puts constraints on the present analysis (Zhang et al., 2023a). We agree that other water quality parameters may be more sensitive to extreme temperatures. Therefore, we have reviewed the relevant literature on the effects of high temperatures on other water quality parameters and the correlation of water quality parameters and enriched the discussion in the section on the effects of high temperatures: "*Although DO and NH_3-N show weak responses under extreme temperatures, other parameters such as salinity, algae, and nutrients are also often highly correlated with COD_{Mn} [70-72]. Consequently, these indicators are likely to exhibit elevated concentration, and patterns have been demonstrated in previous studies [9,14]. Therefore, it is necessary to further confirm the effects of extreme temperature scenarios with available water quality data in the future, proposing strategies to strengthen ecosystem resilience and adaptive management for high-temperature stress.*" (see Lines 377-383 in revised version, Page 22)

Other revisions:

We have updated the format of the references in the manuscript to be consistent with the requirements of the ***Communications Earth & Environment***.

References within this response:

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Response to reviewers

Dear Editors and Reviewers:

We would like to express our sincere gratitude to you and the reviewers for your time, constructive feedback, and support during the review process. We are very pleased that both reviewers found the revised manuscript substantially improved and recommended it for publication. We also appreciate the Editor's careful attention to detail. As requested, we have reviewed the specific editorial comments and requests provided in the attached "Editorial Requests Table."

Below, we provide our detailed responses to the reviewers' final comments.

Reviewer #1:

General comments:

Dear authors,

you did a great job in improving the manuscript. You discussed all issues I raised and revised the text accordingly.

I am fine with the revised version and recommend to publish the manuscript as is.

Reply: We sincerely thank the reviewer for their positive feedback and supportive recommendation. We greatly appreciate your constructive comments during the previous review, which helped us significantly improve the clarity, coherence, and scientific rigor of the manuscript.

Reviewer #2:

General comments:

The authors have extensively integrated the reviewers' feedback, and the revisions have substantially improved the clarity and quality of the manuscript. I am satisfied with the changes that have been made. I support its publication, pending a final check for minor typographical errors.

Reply: We are very grateful to the reviewer for the encouraging evaluation and positive recommendation. Following your suggestion, we have carefully rechecked the entire manuscript to correct minor typographical and formatting inconsistencies. We appreciate your recognition of our efforts to improve the quality of the paper.