

Water-saving strategies across prefectures should target the manufacturing and agriculture sectors in China

Corresponding Author: Dr zongyong zhang

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

Attachments originally included by the reviewers as part of their assessment can be found at the end of this file.

Version 0:

Decision Letter:

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Dear Prof Guan,

Your manuscript titled "High-resolution water datasets show targeted water-saving opportunity in megacities from China" 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. Please highlight all changes in the manuscript text file. In particular, for publication in Communications Earth & Environment we request that you:

- Address the limitations of using national averages for water use efficiencies and possibly explore region-specific data to account for geographic and economic diversity across cities.
- Enhance the discussion by thoroughly engaging with relevant literature concerning environmental regulations and regional differences.
- Demonstrate that your claims are robustly supported; consider performing a sensitivity analysis to offer a range of water use scenarios rather than a single estimated value for each city.

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.

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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,

Rahim Barzegar, PhD
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Martina Grecequet, PhD
Associate Editor
Communications Earth & Environment
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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The authors examined current industrial and agricultural water use efficiencies in 343 Chinese cities using a newly developed high-resolution dataset. The authors then identified room for improving water use efficiencies in specific industrial sectors in specific regions. Based on these findings, water-saving scenarios were built to quantify the volume of water

savings. The manuscript is clearly written and mostly free of errors except for missing punctuation marks in places. However, the following issues need to be addressed before the manuscript can be published.

Some assumptions in scenarios are questionable and could be expanded. For example, the authors used the national sector average to improve water use efficiencies and, thus, potential water savings. However, such assumptions may not be validated, given the geographic diversity across cities. There are reasons why large spatial heterogeneity exists in water withdrawal and efficiencies. The authors also mentioned adopting cutting-edge water efficiency technologies, but it would be more interesting to show the cost of adopting these technologies. A refined scenario analysis could yield much more meaningful and relevant decision outcomes.

While the authors have conducted research competently, the manuscript reads like a technical report. In particular, the discussion section could be improved by engaging with relevant literature to substantiate the authors' statement. The authors cite a reference to environmental regulation by development stage (in line 191) but do not discuss how regulations differ by region. Do more affluent big cities (mostly in coastal cities) have more stringent regulations compared to less affluent, relatively small inland cities? Why are water-intensive industries located in certain cities? What are the characteristics of these cities? How does industrial restructuring relate to water use intensities across cities? A political economy or political ecology perspective could help substantiate the authors' statements.

The maps could be improved. In Figure 1, the authors showed specific cities to make their points. However, they seem to appear islands in either ocean or other countries. I suggest that the authors remove these isolated polygons. Additionally, I am confused about blurry islands shown in the northeast coast. I do not think such islands exist in the ocean. Please remove them. A scale bar should be included at least in one of the maps.

Minor comments

- Line 111. Insert comma after "Thus".
- Line 139. Insert comma before "including".
- Line 168. Change "9" to nine.
- Line 198. Insert comma before "including".
- Line 241. "according to ref". What reference are you referring to?
- Line 261. Any reference to support your statement?
- Line 280. "Insert apostrophe after "years".

Reviewer #2 (Remarks to the Author):

The authors have compiled and analyzed a detailed water use dataset for China for 2015. The dataset covers water use for agricultural and industrial purposes at the "city" level, comprising 343 prefectures, with categorization of water use into 6 groups: agriculture, energy production, manufacturing (3 levels), and services. Water use figures are presented in nationwide maps as well as a series of charts that analyze water use efficiency. Water scarcity forms another key focus of the results and analysis, both for 2015 and for a set of scenarios for 2030-2060. Overall, the paper is well-written and novel, and should be of interest to the scientific community. I recommend some minor revisions and clarifications below.

Specific comments:

- Line 81: The term "city" is used throughout the paper to refer to sub-provincial "prefectures". Given the size of some of the "cities" in western China (Fig. 1), and their agricultural nature in some cases, a different term would probably be better. Prefecture would probably be fine, for example.
- Line 92: Please define the "sector" and sub-sector" terms clearly, and provide more detail. According to the given definition, a "sector" is an economic classification. However, a later line (253) refers to agricultural and industrial sub-sectors, suggesting that agriculture and industry are also "sectors". Other sections of the paper refer to "sub-sectors", which are not defined (e.g. line 124 and line 261). Please also state the total number of sectors represented in the analysis.
- Line 137: How can the study be a "policy tool"? Please revise the wording.
- Data collection is described in the Methods section, and comments will follow below. However, line 144 refers to "point-source surveys" that could be described in greater detail either in the Methods or the Supplemental Materials. I am curious about how water use data are collected, presented, and made available in China.
- Line 150: Efficiency figures like these are not contextualized. Please provide some measure of how such values compare to OECD, US, or world averages? (Figure 5 provides some context, but it is very general).
- Page 6 of 36: Values are provided for industrial and agricultural water use, but not for residential use. Is it possible to provide residential or municipal values?
- Lines 157 and 164: There are some very small values of water use reported here. Are they reliable? What do they say about the quality of data available?
- Line 166: Please state briefly here which measure of water scarcity is used. The explanation can be in the Supplemental Materials, but at least the name should be here.
- Line 180: Is there any indication that water scarcity limits economic productivity?
- Line 191: Are there implications here for the quality of the data? Did you consider a sensitivity analysis or similar approach to determine reasonable ranges of water use, rather than providing only a single "best guess" value for each city? Data are discussed in the Methods, but some points could be added to the discussion.
- Line 227: It would seem obvious to target the least efficient users. Can you explain, even briefly, why this is not done?
- Figure 2: Values are given in RMB here, rather than dollars. It is better to use one consistent currency. Further, are the units

reversed? The figure legend says m³/yuan, but the values seem to be yuan/m³.

- Fig 3. The Supplementary Material provides the codes. Please add this detail to the caption.
- Line 253: The term “scenario” is used here but not defined or explained. What are your scenarios? What specifically do they compare?
- Line 295: What is the National Water Saving Action Regulation? This explanation is not clear.
- Line 310: SI Table 1 could be improved. What is the actual use and efficiency measure? What are comparable global averages or coefficients for the most efficient technology?
- Fig. 4: What does it mean if the grey shaded values (with the axis title on the right-hand side) are below zero? These are compared to the National Average across all sectors? Please explain. Also, the axis title “change of sector numbers (%)” is unclear. What does it mean?
- Fig. 5: Are all the global comparisons fair? Some of the countries listed have small populations and relatively large water supplies. The United States is missing. Slovak and Czech should read Slovakia and Czechia. It is also not clear where the Developed Countries (2030) values come from, what they mean, or how they were calculated. Some Chinese cities have two points and others have only one. Why is this?
- Line 389: There are not unlimited numbers of options in the US.
- Fig. 6 (and elsewhere): In many countries, municipal water systems also provide supply for some industries. Other industries are self-supplied. How was this point handled in the study? Or is the situation different in China?
- Line 449: There is no explanation of (A) here. Just (B) and (C).
- Line 455: Can you provide the relative shares of cities in the case I category versus the case II category? Provinces in case II are listed later (line 484), but more detail here would help.
- Line 463: if the industrial type was not listed (case II), water use was allocated to industries by their value added and water use intensity? How much did assumptions like this affect the totals calculated? Did you conduct a sensitivity analysis to produce even very general figures?
- Fig. 7: Are the frequency values on the right-hand axis correct? Should they be up to 25% rather than 0.25%? The “trendline” is really a smoothed version of the frequency line, isn’t it? Perhaps rename it. Note that the body of the paper around this page seems to become Results rather than Methods. Was that intentional? If it is still methods, rephrasing would help.
- Figure I in the Supplementary Materials is not clear to me.

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Version 1:

Decision Letter:

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Dear Professor Guan,

First of all, please allow me to apologise for the delay in sending a decision on your manuscript titled "High-resolution water datasets show targeted water-saving opportunity in megacities from China". It 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, under the condition that you incorporate supporting evidence from the rebuttal letter into the main manuscript text as suggested by our reviewers.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. For publication in Communications Earth & Environment, we request that you:

*** Include relevant tables (sensitivity analysis) and figures from the response file in either the main text or supplementary materials to enhance clarity and provide complete supporting evidence.

*** Verify that all sections have been thoroughly revised based on reviewer feedback, particularly in areas where outdated terminology or unresolved comments remain. In particular, incorporate your response to reviewers' comments 10, 12, 26, 27 and Table 3 into main text.

***Provide deeper discussion on data quality and improvements (comment 28) and clarify industrial water use (comment 41) as requested by reviewer 2.

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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Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files as a Related Manuscript file.

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

Best regards,

Rahim Barzegar, PhD
Editorial Board Member
Communications Earth & Environment

Martina Grecequet, PhD
Senior Editor,
Communications Earth & Environment
@CommsEarth

REVIEWERS' COMMENTS:

Reviewer #2 (Remarks to the Author):

The authors have significantly improved the manuscript from the first submission. In particular, the methods are expanded

and much clearer. I also appreciate the very detailed comments on the revisions, which run to 53 pages! The article contributes greatly to the available information on water use in China and should be accepted for publication subject to very minor revisions.

A few general remarks follow, before a short list of specific revisions. My original comments on “cities”, methods and Chinese data, sectors vs. sub-sectors, efficiency figures, criticality ratio, water scarcity effects on economic productivity, application of consistent units, and scenario definitions were addressed well. However, many of the responses were confined to the rebuttal itself, while my intention was to highlight points to be revised in the manuscript itself. Specifically, the details in comment 26 would be of interest to the general reader and not just me; residential water use should not be left to a subsequent publication – or if it is, the reasons should be explained to the reader (comment 27); sensitivity analyses are important and the results in the rebuttal should be added to the main manuscript (at least briefly), but my point in Comment 28 was that reported water use by a timber and straw processing company in Liaoyang of 0.046 m³ (46 litres in a year?!) is not believable. This says something about data quality. The paper is very results-oriented, and some deeper remarks on data quality and its improvement would add a useful analytical dimension. There are some thoughtful comments on water policy in the rebuttal that would be useful to add to the manuscript. Response 41 does not really answer my question. Specifically, was it possible to estimate industrial water use for industrial users of municipal sources? Or were these industrial users classified as municipal (and therefore residential) users? I leave it to the editor and associate editor to determine whether these points should be addressed in the manuscript.

Specific comments:

- The authors should explain the addition to the authorship list, Geng Niu. This is already a lengthy authorship list, and all authors should have contributed materially to the study
- Line 107 mentions “city-level” water use. Should this read “prefecture-level”?
- Figure 3’s vertical axis uses “city”. Please ensure that “city” and “prefecture” are used consistently.
- Figure 4’s caption has an “&”. I do not know what this means
- Lines 373 and 374: what is the difference between cloth manufacturing and clothing manufacturing in practical terms? Do they occur in different regions? Do they use significantly different volumes of water, or is their water intensity different? The reader will wonder why they are listed separately.
- Line 515 mentions “city” again. It appears that this section was not revised with the prefecture term
- Please explain the “IPCC” acronym and cite a reference where it first appears

Reviewer #3 (Remarks to the Author):

Review for the paper entitled: “High-resolution water datasets show targeted water-saving opportunity in megacities from China”.

Thanks for responding to the comments. The comments were answered perfectly in the response to the comments file. However, for some comments, the explanations should be added to the manuscript as well. The related tables should either be added to the main manuscript or the supplementary materials.

Comment 1 (9 in the response file): Four steps (limitations) were mentioned enough and concisely.

Comment 2 (10 in r s file): The answer to the comment is very perfect; however, please bring these explanations in the corresponding section of the manuscript as well (I believe the introduction). Some tables and figures are available in the response to the comments but not in the main manuscript or the supplementary materials. For example, “R. Table 3:

Comment 3 (11 in r s file): The manuscript now is more paper-wised.

Comment 4 (12 in r s file): You responded very in detail which is good but please bring these explanations in the manuscript, concisely.

Comment (13 in r s file): The figure was modified and improved.

Minor comments 6 to 12 (14 to 20 in r s file): Responded.

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Review for the paper entitled: “**High-resolution water datasets show targeted water-saving opportunity in megacities from China**”.

Thanks for responding to the comments. The comments were answered perfectly in the response to the comments file. However, for some comments, the explanations should be added to the manuscript as well. The related tables should either be added to the main manuscript or the supplementary materials.

Comment 1(9 in the response file): Four steps (limitations) were mentioned enough and concisely.

Comment 2 (10 in r s file): The answer to the comment is very perfect; however, please bring these explanations in the corresponding section of the manuscript as well (I believe the introduction). Some tables and figures are available in the response to the comments but not in the main manuscript or the supplementary materials. For example, “R. Table 3:

Comment 3 (11 in r s file): The manuscript now is more paper-wised.

Comment 4 (12 in r s file): You responded very in detail which is good but please bring these explanations in the manuscript, concisely.

Comment (13 in r s file): The figure was modified and improved.

Minor comments 6 to 12 (14 to 20 in r s file): Responded.

For publication in Communications Earth & Environment we request that you:

- Comment 1: • Address the limitations of using national averages for water use efficiencies and possibly explore region-specific data to account for geographic and economic diversity across cities.

– Response 1: We have revised the manuscript to address the limitations more clearly.

In our first step, i.e., the process of accounting, we incorporated both geographic and economic diversity. Variability of intensity for each prefecture was considered for regionalization of water withdrawal. China's prefectures showcased distinctive characteristics in terms of age, size, coverage, population, resource endowment and industrial drivers, and this heterogeneity indicated different economic development levels^{1,2}. Hence, we tuned water withdrawal based on local statistics, such as gross water withdrawal in each type, for calibration. This calibration reflected local water status accurately. Even in *Case 2*, where not all data were available, differences between prefectures were considered and intensities of economically and demographically similar regions were used to estimate for prefectures at a similar stage³. Thus, our datasets may be more advanced than those in the three previous studies⁴⁻⁶, which assumed agriculture-, industry-, construction- and service-water withdrawal intensities were identical for every city, and even transferred information and data of rich cities to serve for poor cities. For example, because implementation of its WA+ framework did not necessarily require local-measured or representative indicators or efficiency data, the previous study results⁵ should suffer from substantial biases.

For water-saving analyses, actually, the 'national sector-average level' indicator is extensively cited in recent literature on water-saving strategies, and utilized in policy regulations, within China and globally^{7,8}. 1) Some latest 2024 studies have set the same national sector-average levels as goals for industrial sectors^{7,9}. Among them, She et al. (2024) consider that the averages could reflect fairness, feasibility, and effectiveness of improvement⁷. 2) This numerical measure is also applied to underpin regulations at the prefecture level. For example, some regulations in Shanghai city utilize the averages or optimal values, as the highest technical standards since 2019, which is potential for nationwide promotions¹⁰. In prefectures, such as Chongqing, Shenzhen and Weinan, the continuous 2019-2024 plans, as well as implementations of the *National Water-Saving Action*, rule total water-use per GDP lower than 40% of national averages^{11,12}, and industrial water-use per value-added lower than 40%-50% of national averages. Since 2019, such average requirements have been continuously implemented and completed by prefecture-level Bureaus of Industry and Information Technology, along with Statistic and Economic Information Commission, Bureaus of Water Resources, Development and Reform Commission, and district-level governments. For example, in Shenzhen city in 2022, total water-use per GDP is reduced to 4.57 m³ per k US\$, which equals one eighth of the national average level. 3) this indicator is broadly used in guiding water efficiency, as listed in many technical standards and requirements for water-saving assessment of planning and constructing projects¹⁰, which are released by the Ministry of Water Resources in China. The 'three-redline' water stringent-regulations have also established to approach globally optimal levels of water-use intensities by the year of 2030. 4) this treatment is also referred to carbon-emission reduction, which should be accessible^{13,14}.

An advantage of these 'national sector-average' requirements is motivating competition among regional governments through large-scale water-use accounting and macro benchmarking, as the latest references stressed^{15,16}. According to these latest references^{15,16}, such national comparisons merit attention beyond stereotypes of conventional and provincial models, and could denote identical criteria to discover and improve the most wasteful usages of water. On the contrary, the most outdated water-users could not be identified or updated without such comparisons. Previous

literatures are basically limited to specific-region analyses through case-study or pilot analyses, i.e., within a certain province, prefecture^{9,17}, or plant^{18–20}, which could not be integrated. This study aims to explore opportunity for water saving under a general benchmark. To construct macro datasets, it has selected as many as 16 driving forces for 63 national-sectors, and connected a size indicator with corresponding water-use efficiency, which have covered 100% water users for agricultural crops and industrial outputs all over China. We identified 180 water-scarce prefectures, and then compared water-use efficiencies in these 180 specific and water-scarce prefectures. Moreover, this study takes one step further by comparing within each one national-sector, rather than the broad GDPs, particularly focusing on the key water-consumptive sectors. The ‘water-use per GDP’ indicator compares different national-sectors within a certain region, and could not take into consideration different and dominant sub-sectors or processes. This issue has been raised by studies⁹.

In our results, we do find there are common characteristics, features and similarities in the targeted prefectures for water-saving (as listed in the Supplementary Table 3). These similarities provide justification for our use of the ‘national sector-average’ approach. Concretely, 1) they are faced with common challenges, such as water scarcity, pollution, and vulnerability to extreme weather events. For example, over-extraction of groundwater is a critical issue in these prefectures, leading to significant drops in groundwater levels and deterioration of water quality. 2) for agricultural-related prefectures, agricultural practices in these prefectures often involve inefficient irrigation methods, leading to high water wastage. Traditional flood irrigation is still prevalent, which is not sustainable in the long term. There is a lack of widespread adoption of water-saving technologies like drip irrigation and rainwater harvesting in many of these regions. 3) for industrial-related prefectures, i.e., Guangzhou, Shantou, Zhongshan, Huai’an, Suzhou, Taizhou, Hefei, and Nanjing, in terms of climate type, these prefectures are mostly located in the east and south of China, and fall into the subtropical monsoon climate zone. Their climate commonly exhibits distinct seasons, with hot and rainy summers vs. Cold and dry winters. Precipitations of these prefectures are commonly dominated by monsoonal circulation. Distribution and amount of precipitation are commonly subject to strongness and direction of monsoonal circulation change. 4) to address the common challenges is critical for future sustainability and health of the cities. Efforts to manage resources more effectively and improve water quality, are essential to mitigate the adverse impacts.

Last but not least, the new accounting for water-use data in this study is emerging, and should be promising in future²¹, as stressed by a report of 2050 Water Priorities for the USA on Future Directions, by the *National Academies of Sciences, Engineering, and Medicine* of America²². Our advancements in these methods and accounts have independently influenced several newly-published studies in the field. This impact is evident in the following studies. She et al. (2024) has reviewed the research gap and pointed out unavailability of detailed water-use data at the subsector level, then it stressed that, our methodology should be used to construct the water use accounts to severely robust its own conclusions. Its numerical results may be uncertain, due to assumptions made in the absence of the prefecture-level water-use data⁷. Other latest research in 2023-2024 also stressed the value of such accounting^{7,17}, because it is a real problem for water issues of China. Among these, a research by the University of Twente from the Netherlands, also specifically pointed out necessity for high-resolution water-use datasets, in terms of detailed economic-sectors, which is a current data gap²³.

In summary, the ‘national sector-average’ measurement and comparison should make sense⁷. We have also revised accordingly.

- Comment 2: • Enhance the discussion by thoroughly engaging with relevant literature concerning environmental regulations and regional differences.

– Response 2: thank you for your kind recommendation. We read through both the new literatures and our own manuscript, then tried to revise the relevant parts. For details, please refer to discussions in the bullet i.) of responses to Question No.12#.

We carefully reviewed recent literature and revised the discussion accordingly. Our revisions emphasize the varying stringency of environmental regulations across regions. Affluent coastal cities generally implement stricter water-use policies, while smaller inland cities adopt more lenient regulations to promote economic growth. These regulatory differences shape the distribution of water-intensive industries, which tend to cluster in inland areas where policies are more relaxed.

- Comment 3: • Demonstrate that your claims are robustly supported; consider performing a sensitivity analysis to offer a range of water use scenarios rather than a single estimated value for each city.

– Response 3: Thank you for your kind recommendation. We have supplemented to perform such sensitivity analyses as required.

For method validation, we referred to and used procedures in previous studies^{24,25}. Overall, for *Case 2* on estimation for prefectures without water withdrawal statistics, water withdrawal efficiency was a key uncertainty. We conducted sensitivity analyses by replacing these efficiency data with regional efficiency. The regional efficiency data were from provincial and regional Water Resources Bulletins.

Concretely, we estimate the sensitivity of water withdrawal by agriculture, industry, and services for prefectures, by replacing the specific intensity value with regional, provincial or national magnitudes based on data availability. We take the prefectures of Anhui, Jiangsu, and Zhejiang as examples, because their Water Resources Bulletin did not provide water withdrawal for the six types for some of their prefectures.

For agricultural water withdrawal, one assumption is applied for prefectures without statistical information: If there is no available irrigation water-withdrawal per mu for farmland, the water withdrawal intensity for the agriculture sector would be the same. We conduct a sensitivity analysis by replacing the intensity with the regional or provincial values, the results of which are shown below:

R. Table 1 Sensitivity analysis of agricultural water withdrawal

Prefecture	Original agricultural water withdrawal (10 ⁶ m ³)	Irrigation area (10 ³ hectare)	Irrigation water withdrawal (m ³) per mu for farmland	Replaced agricultural withdrawal for sensitivity test (10 ⁶ m ³)	Percentage difference (%)
Hefei	1503	458	282	1295	13.9
Bengbu	778	237	282	670	13.9
HuaiBei	468	143	282	403	13.9
Tongling	268	82	282	231	13.9
Huangshan	168	51	282	145	13.9

Suzhou	1384	422	282	1192	13.9
Xuancheng	658	201	282	567	13.9
Wuxi	610	173	461	711	-14.3
Xuzhou	4086	1161	389	4024	1.6
Changzhou	756	215	461	882	-14.3
Nantong	2942	836	389	2898	1.5
Lianyungang	2231	634	389	2197	1.6
Huai'an	2801	796	389	2758	1.6
Zhenjiang	831	236	389	818	1.5
Taizhou	2046	581	389	2015	1.5

Note: The percentage difference is calculated as (column2- column5)÷column2*100%. + and - are determined by whether actual intensity of selected sample is higher than the provincial average or not in their respective sector. Table 1 is for agriculture and Table 2 is for industry. Table 1 and Table 2 are somehow separated or independent from each other.

Although the largest differences between *Agricultural water withdrawal*' (estimated with the replaced agricultural water withdrawal intensity) and our original estimation appeared in Wuxi and Changzhou (-14.3%) in R. Table 1, the average variation of the absolute value was 9.0%. This result indicates that there are no substantial differences, and our method provides a credible estimation of agricultural water withdrawal.

R. Table 2 Sensitivity analysis of industrial water withdrawal

Prefecture	Original industrial water withdrawal (10 ⁶ m ³)	Industrial value added (10 ⁹ \$)	Industrial water withdrawal (m ³) per k \$ value-added	Replaced industrial withdrawal for sensitivity test (10 ⁶ m ³)	Percentage difference (%)
Hefei	964	33	30.7	1011	-4.8
Bengbu	291	10	30.7	305	-4.8
Huaibei	214	7	30.7	225	-4.8
Tongling	185	6	30.7	194	-4.8
Huangshan	54	2	30.7	57	-4.8
Suzhou	157	5	30.7	165	-4.8
Xuancheng	176	6	30.7	184	-4.8
Wuxi	520	43	10.2	502	3.7
Xuzhou	477	40	12.3	552	-13.5
Changzhou	461	38	10.2	444	3.7
Nantong	511	43	9.5	467	9.5
Lianyungang	204	17	12.3	236	-13.5
Huai'an	261	22	12.3	302	-13.5
Zhenjiang	358	30	9.5	327	9.5
Taizhou	434	36	9.5	397	9.5

Note: For prefectures in Anhui, we could obtain only the industrial value-added for the above-designated-sized enterprises.

For the industrial water withdrawal estimation, although the largest differences between *Industrial water withdrawal*' (estimated with the replaced water withdrawal intensity) and our original estimation appeared in Xuzhou, Lianyungang, and Huai'an (-13.5%) in R. Table 2, the average variation in the absolute value was 7.3%. This result indicates that there is relatively low sensitivity, and the method provides a credible estimation of industrial water withdrawal. Moreover, the prefectures were the same as those selected for the validation of agricultural water withdrawal, which also supports the robustness of our method.

Similarly, for services, we assumed that the water withdrawal per employee would be equal within a prefecture (for prefectures with statistical information) or among prefectures (for those without). We estimated the uncertainty of other services using water withdrawal per employee at the national level from the prefectures with statistical information. The list of prefectures used is provided in Appendix. We observed that the average variation was 8.0%. This result indicates that there are no large differences, and the method provides an accurate and credible estimation on service water withdrawal. In fact, similar proportions were also used in the estimations of the *China Institute of Water Resources and Hydropower Research*^{26–28}.

Finally, given that China did not officially report statistics on environmental sanitation areas at this stage, we omitted the validation of environmental water withdrawal. Nevertheless, this would be possible when such data are available, considering that many prefectures are beginning to explore how to estimate their environmental-sanitation areas.

- Comment 4: 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.

– Response 4: Thank you for your kind support and openness to discuss. If you find any inappropriate, please tell us. We are happy to communicate and improve this manuscript further. Thank you again for your patience.

- Comment 5: EDITORIAL POLICIES AND FORMATTING: We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article. Editorial Policy: [Policy requirements](#) (Download the link to your computer as a PDF.). Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist: [Communications Earth & Environment formatting checklist](#) and also in our style and formatting guide [Communications Earth & Environment formatting guide](#) .

– Response 5: Thank you. We have reviewed the detailed formatting requirements, and confirmed compliance with them.

- Comment 6: * DATA: Communications Earth & Environment endorses the principles of the Enabling FAIR data project (<http://www.copdess.org/enabling-fair-data-project/>). We ask authors to make the data that support their conclusions available in permanent, publically accessible data repositories. (Please contact the editor if you are unable to make your data available).**

– Response 6: Thanks. We have cited our *Scientific Data* paper accordingly^{29,30}.

- Comment 7: All Communications Earth & Environment manuscripts must include a section titled "Data Availability" at the end of the Methods section or main text (if no Methods). More

information on this policy, is available at <http://www.nature.com/authors/policies/data/data-availability-statements-data-citations.pdf>. In particular, the Data availability statement should include: - Unique identifiers (such as dois and hyperlinks for datasets in public repositories)- Accession codes where appropriate- If applicable, a statement regarding data available with restrictions- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement. DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at <http://www.nature.com/sdata/policies/repositories>. If a community resource is unavailable, data can be submitted to generalist repositories, such as [figshare](#) or [Dryad Digital Repository](#). Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section. Please refer to our data policies at <http://www.nature.com/authors/policies/availability.html>.

— Response 7: Thanks. We have added these. Doi: <https://doi.org/10.6084/m9.figshare.c.6394068.v1>.

REVIEWER COMMENTS: Reviewer #1 (Remarks to the Author):

- Comment 8: The authors examined current industrial and agricultural water use efficiencies in 343 Chinese prefectures using a newly developed high-resolution dataset. The authors then identified room for improving water use efficiencies in specific industrial sectors in specific regions. Based on these findings, water-saving scenarios were built to quantify the volume of water savings. The manuscript is clearly written and mostly free of errors except for missing punctuation marks in places. However, the following issues need to be addressed before the manuscript can be published.

– Response 8: Thank you for your constructive suggestions. We read through our manuscript to supplement such punctuation marks.

- Comment 9: Some assumptions in scenarios are questionable and could be expanded. For example, the authors used the national sector average to improve water use efficiencies and, thus, potential water savings. However, such assumptions may not be validated, given the geographic diversity across cities. There are reasons why large spatial heterogeneity exists in water withdrawal and efficiencies.

– Response 9: We appreciate your criticism. Indeed, we acknowledge the geographic and economic diversity. We have revised the manuscript to address the limitations more clearly in this regard.

In our first step, i.e., the process of accounting, we incorporated both geographic and economic diversity. Variability of intensity for each prefecture was considered for regionalization of water withdrawal. China's prefectures showcased distinctive characteristics in terms of age, size, coverage, population, resource endowment and industrial drivers, and this heterogeneity indicated different economic development levels^{1,2}. Hence, we tuned water withdrawal based on local statistics, such as gross water withdrawal in each type, for calibration. This calibration reflected local water status accurately. Even in *Case 2*, where not all data were available, differences between prefectures were considered and intensities of economically and demographically similar regions were used to estimate for prefectures at a similar stage³. Thus, our datasets may be more advanced than those in the three previous studies⁴⁻⁶, which assumed agriculture-, industry-, construction- and service-water withdrawal intensities were identical for every city, and even transferred information and data of rich cities to serve for poor cities. For example, because implementation of its WA+ framework did not necessarily require local-measured or representative indicators or efficiency data, the previous study results⁵ should suffer from substantial biases.

For water-saving analyses, actually, the 'national sector-average level' indicator is extensively cited in recent literature on water-saving strategies, and utilized in policy regulations, within China and globally^{7,8}. 1) Some latest 2024 studies have set the same national sector-average levels as goals for industrial sectors^{7,9}. Among them, She et al. (2024) consider that the averages could reflect fairness, feasibility, and effectiveness of improvement⁷. 2) This numerical measure is also applied to underpin regulations at the prefecture level. For example, some regulations in Shanghai city utilize the averages or optimal values, as the highest technical standards since 2019, which is potential for nationwide promotions¹⁰. In prefectures, such as Chongqing, Shenzhen and Weinan, the continuous 2019-2024 plans, as well as implementations of the *National Water-Saving Action*, rule total water-use per GDP lower than 40% of national averages^{11,12}, and industrial water-use per value-added lower than 40%-50% of national averages. Since 2019, such average requirements have been continuously implemented and completed by prefecture-level Bureaus of Industry and Information Technology, along with Statistic and Economic Information Commission, Bureaus of Water Resources, Development and Reform Commission, and district-level governments. For

example, in Shenzhen city in 2022, total water-use per GDP is reduced to 4.57 m³ per k US\$, which equals one eighth of the national average level. 3) this indicator is broadly used in guiding water efficiency, as listed in many technical standards and requirements for water-saving assessment of planning and constructing projects¹⁰, which are released by the Ministry of Water Resources in China. The ‘three-redline’ water stringent-regulations have also established to approach globally optimal levels of water-use intensities by the year of 2030. 4) this treatment is also referred to carbon-emission reduction, which should be accessible^{13,14}.

An advantage of these ‘national sector-average’ requirements is motivating competition among regional governments through large-scale water-use accounting and macro benchmarking, as the latest references stressed^{15,16}. According to these latest references^{15,16}, such national comparisons merit attention beyond stereotypes of conventional and provincial models, and could denote identical criteria to discover and improve the most wasteful usages of water. On the contrary, the most outdated water-users could not be identified or updated without such comparisons. Previous literatures are basically limited to specific-region analyses through case-study or pilot analyses, i.e., within a certain province, prefecture^{9,17}, or plant^{18–20}, which could not be integrated. This study aims to explore opportunity for water saving under a general benchmark. To construct macro datasets, it has selected as many as 16 driving forces for 63 national-sectors, and connected a size indicator with corresponding water-use efficiency, which have covered 100% water users for agricultural crops and industrial outputs all over China. We identified 180 water-scarce prefectures, and then compared water-use efficiencies in these 180 specific and water-scarce prefectures. Moreover, this study takes one step further by comparing within each one national-sector, rather than the broad GDPs, particularly focusing on the key water-consumptive sectors. The ‘water-use per GDP’ indicator compares different national-sectors within a certain region, and could not take into consideration different and dominant sub-sectors or processes. This issue has been raised by studies⁹.

In our results, we do find there are common characteristics, features and similarities in the targeted prefectures for water-saving (as listed in the Supplementary Table 3). These similarities provide justification for our use of the ‘national sector-average’ approach. Concretely, 1) they are faced with common challenges, such as water scarcity, pollution, and vulnerability to extreme weather events. For example, over-extraction of groundwater is a critical issue in these prefectures, leading to significant drops in groundwater levels and deterioration of water quality. 2) for agricultural-related prefectures, agricultural practices in these prefectures often involve inefficient irrigation methods, leading to high water wastage. Traditional flood irrigation is still prevalent, which is not sustainable in the long term. There is a lack of widespread adoption of water-saving technologies like drip irrigation and rainwater harvesting in many of these regions. 3) for industrial-related prefectures, i.e., Guangzhou, Shantou, Zhongshan, Huai’an, Suzhou, Taizhou, Hefei, and Nanjing, in terms of climate type, these prefectures are mostly located in the east and south of China, and fall into the subtropical monsoon climate zone. Their climate commonly exhibits distinct seasons, with hot and rainy summers vs. Cold and dry winters. Precipitations of these prefectures are commonly dominated by monsoonal circulation. Distribution and amount of precipitation are commonly subject to strongness and direction of monsoonal circulation change. 4) to address the common challenges is critical for future sustainability and health of the cities. Efforts to manage resources more effectively and improve water quality, are essential to mitigate the adverse impacts.

Last but not least, the new accounting for water-use data in this study is emerging, and should be promising in future²¹, as stressed by a report of 2050 Water Priorities for the USA on Future Directions, by the *National Academies of Sciences, Engineering, and Medicine* of America²². Our advancements in these methods and accounts have independently influenced several newly-published studies in the field. This impact is evident in the following studies. She et al. (2024) has

reviewed the research gap and pointed out unavailability of detailed water-use data at the subsector level, then it stressed that, our methodology should be used to construct the water use accounts to severely robust its own conclusions. Its numerical results may be uncertain, due to assumptions made in the absence of the prefecture-level water-use data⁷. Other latest research in 2023-2024 also stressed the value of such accounting^{7,17}, because it is a real problem for water issues of China. Among these, a research by the University of Twente from the Netherlands, also specifically pointed out necessity for high-resolution water-use datasets, in terms of detailed economic-sectors, which is a current data gap²³.

In summary, the ‘national sector-average’ measurement and comparison should make sense⁷. We have also revised accordingly. We think the prefectural and subsector heterogeneity in water withdrawal efficiency highlights that, for some sector-prefecture combinations, drastically more water consumption and environmental impact occur than making the same product elsewhere (i.e., industrial competitiveness is hindered). Thus, for high water-intensity sector-prefecture combinations, according to the law of diminishing marginal utility, marginal water-saving costs should be small, and potential for water-efficiency improvements should be large. A lack of consideration of regional and sectoral heterogeneity would result in increased management costs for water savings including land costs, rental income, opportunity costs, and other social costs^{31,32}. For example, in terms of water efficiency, some prefectures, such as Harbin and Changchun, fall behind in chemical production, but are relatively advanced in agriculture; while others including Daqing, have advantage in industry, but are less-efficient in rice cultivation.

During this period, we read through the latest literatures^{7,33}, and tried our best to expand our scenario analyses as you kindly required, yet at this stage, we find substantial difficulty in obtaining or mapping such fined or detailed technical data as for each prefecture or sector³¹, i.e., specific techniques, accurate water-use amount for industrial output (\$) or agricultural crop (or irrigated area, in m²), water-saving coefficient and cost⁷. For details, please refer to discussions in responses to Question No.10# below.

- Comment 10: The authors also mentioned adopting cutting-edge water efficiency technologies, but it would be more interesting to show the cost of adopting these technologies. A refined scenario analysis could yield much more meaningful and relevant decision outcomes.

– Response 10: Thank you for your suggestions. To address this issue comprehensively, we provide a combined discussion of (i.) the methodology and (ii.) the associated costs.

i.) we may wish to supplement some clarifications on our methodology firstly. For all the data presented in this study, we need to develop a general framework, to realize estimation on detailed and subsector water use. Unfortunately, for the time being, few published data on water-use exist, although China’s water issues are of international interest. As of 2024, as a foundation for water accounting, full monitoring or metering on agricultural water-use remains inadequate and needs to be supplemented, according to the National Development and Reform Commission of China, etc.^{22,34}. Additionally, as Qi et al. (2022) has pointed out that, new irrigation infrastructures have mainly been constructed in the water-scarce regions of China³⁵, suggesting a further necessity to save water in such specific water-scarce areas. That’s why in 2023, the Chinese government has devoted more than 2,435 million US\$ into improvements in as many as 581 irrigation areas, which increased by 7%, compared with 2022 investment amount.

With regard to our methodology, we supplement in our main text that ‘Core and primary data of the Dataset on Water Use of China at the Sub-sector level (DWUCs) are from national pollution point-source census of the Ministry of Ecology and Environment. In the census and survey, we

investigated 161,598 companies (approximately 42% of all above designated-size companies of China; above designated-size company referred to those with annual business revenue over 2.93 million US\$³⁶; exchange rate at US\$1 = ¥ 6.8174). Apart from carbon emissions, water withdrawal information collection was conducted, and industrial economic-output data were coupled with water-withdrawal data of companies. Then these data were subsequently aggregated according to sub-sectors to calculate the intensities, i.e., water withdrawal intensities for individual sub-sectors in each prefecture across 13,377 industrial sub-sectors for all 343 prefecture-level cities.

Our methodology applies a water balance principle between prefectures and provinces, i.e., water balance equations between provincial water use and its administered prefectures' water-use amounts³⁷. Adopted from the IPCC principles and elements, construction of our datasets was based on selection of 16 driving forces, according to each broad type. For example, disaggregated industrial output and water withdrawal per output of each sub-sector (*Intensity*). We connected a size indicator with corresponding water-withdrawal efficiency. Mechanisms of accountings for the other sectors are similar.

First of all, we need to do data-mining aiming at the 16 indicators, mainly from provincial and prefecture-level water resources bulletins issued by the *Ministry of Water Resources* and local *Hydrology and Water Resources Investigation Bureaus*, national pollution source census and regular reporting systems of the Ministry of Ecology and Environment, and provincial and prefecture-level statistical yearbooks (Figure 7). Then, we move into detailed estimations. We used a complete set of equations to describe all variables. Specifically, ① industrial water use (*WaterIndus*) accounting is as follows: we followed three procedures (A-C), and realized the prefecture level (B) partition, and then the sub-sector level (C).

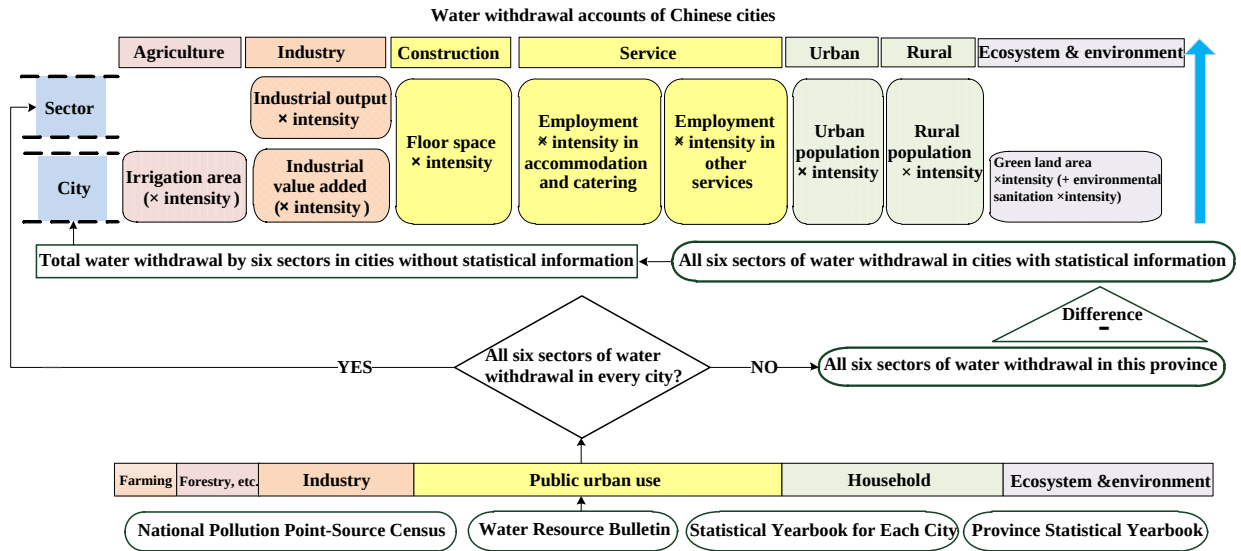


Fig. 7. A framework for subsector water withdrawal accounting at the prefecture level. The circled sources at the bottom indicate the primary data inputs used for estimation. This is in furtherance to our previous paper³⁸.

For (A), we compiled industrial water withdrawal for prefectures in a province from provincial water resources bulletins. There were two cases to consider based on data availability (please also see Figure 7 for intuitive illustrations):

Case 1) If water resources bulletin for a province provided industrial water withdrawal for every administrative prefecture, these data were compiled for later use in subsector partition. We allocated water withdrawal into each disaggregated sub-sector (in Supplementary Table 1) for each prefecture.

Case 2) If the water resources bulletin did not provide water withdrawal for industrial type for all administrative prefectures, we collected industrial water-withdrawal for each prefecture in their corresponding water resources bulletins. For those prefectures that did not have these data in their respective bulletins, we calculated the difference between provincial water withdrawal and the sum of water withdrawal for all prefectures that did have statistics in their prefecture-level water resources bulletins, based on a water mass balance. In this way, we obtained a sum for all prefectures for which water withdrawal of industrial type was not included in their water resources bulletins.

For **(B)**, we allocated the sum of industrial type for those prefectures without statistics, based on two multipliers as driving forces of water withdrawal. We used total industrial value-added (*Valueadded*, size indicator) multiplying water withdrawal per value-added (*Intensity_i*) in the partition. According to data availability, for prefectures having data for both water withdrawal per value-added and total industrial value-added, we immediately obtained:

$$W_i = Valueadded_i \times Intensity_i / \sum_{i=1}^n (Intensity_i \times Valueadded_i) \quad (1)$$

$$WaterIndus_i = W_i \times SUM_{n_cities} \quad (2)$$

where i is a prefecture without statistics in the province and n represents the total number of prefectures without statistics in the same provinces. Industrial water withdrawal per value-added was sourced from water resources bulletins at the province and prefecture levels³⁹. Total industrial value-added was from province or prefecture statistical yearbooks. This case was considered to be a further step, going beyond previous studies, such as Guan et al. (2014)⁶, which assumed industrial water withdrawal per value-added was identical amongst regions. In the case of missing water intensity, we instead used total industrial value-added to calculate proportions to disaggregate water withdrawal.

For **(C)**, we used disaggregated industrial output and water withdrawal per output of each sub-sector (*Intensity_{i,k}*) to partition total industrial water withdrawal of each prefecture (*WaterIndus_i*). That is,

$$W_{i,k} = Intensity_{i,k} \times Output_{i,k} / \sum_{k=7}^{45} (Intensity_{i,k} \times Output_{i,k}) \quad (3)$$

$$WU_{i,k} = W_{i,k} \times WaterIndus_i, k \in [7, 45] \quad (4)$$

where k represents a sub-sector of prefecture i , and $WU_{i,k}$ is the subsector industrial water withdrawal of prefecture i . $W_{i,k}$ is the proportion of subsector and industrial water withdrawal in total industry water withdrawal. *Intensity_{i,k}* is the disaggregated water withdrawal intensity.

Output_{i,k} is subsector and industrial output of each sub-sector. *WaterIndus_i* is total industrial water withdrawal of prefecture i . Subsector industrial outputs were sourced from the statistical yearbook for each prefecture. These data were then proofed and corrected by the authors, according to the China City Statistical Yearbook. We regarded the China City Statistical Yearbook as

consistent and true magnitudes. Industrial total water withdrawal and water-withdrawal per value-added were collated from water resources bulletins at province and prefecture levels.

In the prefecture module, methods of accountings for the other sectors' water use are similar as Industry. Concretely, ② estimation on agriculture water-use amount equates,

$$WU_{i,k} = Irriareas_{i,k} \times Intensity_{i,k}, k \in [1,5] \quad (5)$$

We used the irrigation water withdrawal per *mu* of farmland, and the irrigation area to determine agricultural water use. $WU_{i,k}$ is irrigation water withdrawal of prefecture *i* for agriculture, $Irriareas_{i,k}$ is irrigation area of prefecture *i* for agriculture (represented by farming), and $Intensity_{i,k}$ is irrigation water withdrawal per *mu* of prefecture *i* (*mu* is Chinese acre, 1 *mu* ≈ 667 m²). 1-5 denote the first five of 63 economic activities. Irrigation area was from provincial statistical yearbooks. Irrigation water withdrawal per *mu* for farmland was sourced from water resources bulletins at the province and prefecture levels³⁹. As there is little uncertainty, this case is considered an advancement of previous studies, such as Vardon et al. (2007)⁴, which used only the irrigation area by assuming that the irrigation water withdrawal efficiency was equal among regions.

③ we utilized the floor space of housing (*Flospac*), and the water withdrawal per unit (*Intensity*) to estimate water withdrawal for construction. Estimation on construction water-use amount equates,

$$WU'_{i,46} = Flospac_{i,46} \times Intensity_{i,46} \quad (6)$$

where $WU'_{i,46}$ is original water withdrawal of prefecture *i* for construction, $Flospac_{i,46}$ is floor space area of housing of prefecture *i* for construction (represented by completed floor space), and $Intensity_{i,46}$ is water withdrawal per floor-space area of housing of prefecture *i*. Water withdrawal per floor space of housing completed was from the Bulletin of 1st Water Resources Census (i. e., 2nd Water Resources Census of Shanghai by the Shanghai Bureau of Statistics and Water Authority). Floor space of housing was from provincial statistical yearbooks.

④ For water withdrawal for accommodation & catering sector, which is usually the largest water user in the service, we assumed a positive correlation between water use and the number of employees, and then used employment and water withdrawal per employee (*Intensity*). Estimation on service water-use amount equates,

$$WU'_{i,49} = Employment_{i,49} \times Intensity_{i,49} \quad (7)$$

$$WU'_{i,k} = Employment_{i,k} \times Intensity_{i,k}, k \in [47,48] \cup [50,60] \quad (8)$$

$WU'_{i,49}$ is original water withdrawal of prefecture *i* for accommodation & catering sub-sector, $Employment_{i,49}$ is number of employees of prefecture *i* for accommodation & catering sub-sector (as key water user), and $Intensity_{i,49}$ is water withdrawal per employee of prefecture *i*. Similarly, $WU'_{i,k}$ is original water withdrawal of prefecture *i* for the other services other than accommodation & catering sub-sector (as ordinary water users), $Employment_{i,k}$ is number of

employees of prefecture i for the other services other than accommodation & catering sub-sector, and $Intensity_{i,k}$ is water withdrawal per employee of prefecture i . Water withdrawal per capita in representative accommodation & catering, water withdrawal per capita in other services, were from the Bulletin of 1st Water Resources Census (i. e., 2nd Water Resources Census of Shanghai by the Shanghai Bureau of Statistics and Water Authority). The number of employees in accommodation & catering and other services were from China City Statistical Yearbook.

⑤ we used the rural population ($Popul$, permanent residents), and household water withdrawal per resident in rural areas ($Intensity$) to estimate rural household water withdrawal. The estimation for urban household water withdrawal was quite similar. Estimation on household water-use amount equates,

$$WU'_{i,k} = Popul_{i,k} \times Intensity_{i,k} \quad (9)$$

$$W_{i,k} = WU'_{i,k} / \sum_{k=61}^{62} WU_{i,k}, k \in [61, 62] \quad (10)$$

where $WU'_{i,k}$ is original water withdrawal of prefecture i for household, $Popul_{i,k}$ is rural (or urban) population of prefecture i (represented by number of permanent residents), and $Intensity_{i,k}$ is household water withdrawal per resident in rural (or urban) areas of prefecture i .

$W_{i,k}$ is the proportion of rural (or urban) household water withdrawal in total household water withdrawal. Rural and urban population (permanent resident) were from provincial statistical yearbooks. Household water withdrawal per capita in both rural and urban areas were from province or city statistical yearbooks.

After completing prefecture module estimations, subsector module equations contain,

⑥ estimation on construction and service water-use amounts equate,

$$WU_{i,k} = WU'_{i,k} / \sum_{k=46}^{60} WU'_{i,k} \times (WU_{i,UrbanPublic}), k \in [46, 60] \quad (11)$$

We used the proportions of water withdrawals (original magnitude indicated by $WU'_{i,k}$) in construction, accommodation & catering and other services, to separate urban and public water withdrawal. This procedure is more plausible than that used in Guan et al. (2014)⁶, which assumed that the water efficiencies of construction and all services were the same. $WU_{i,k}$ is disaggregated and subsector water withdrawal for construction and services of prefecture i . $WU'_{i,k}$ is the original and subsector water withdrawal for construction and services of prefecture i . $WU_{i,UrbanPublic}$ is total urban and public water withdrawal of prefecture i . Please note that the public water withdrawal in urban areas is defined as the sum of the water withdrawal for construction and all the services. This definition of water withdrawal is a statistical feature that is different from other energy, resource or economic statistics.

⑦ estimation on household water-use amount equates,

$$WU_{i,k} = W_{i,k} \times WU_{i,Household}, k \in [61, 62] \quad (12)$$

$W_{i,k}$ is the proportion of rural (or urban) household water-withdrawal in total household water-withdrawal. It is used to partition total household water-withdrawal into rural and urban household sub-sectors, on an occasion that we could only get a total number of household water-withdrawal.

$WU_{i,k}$ is disaggregated and subsector water-withdrawal for rural or urban household of prefecture

i . $WU_{i,Household}$ is total household water-withdrawal of prefecture i .

⑧ we used the area of green land, irrigation volume per green-land area (*Intensity* equals 0.0782 cubic meters), environmental sanitation areas (*Sanitarea*), and the water withdrawal per unit (*Intensity'* equals 0.0265 cubic meters) to estimate ecosystem and environment preservation water-withdrawal. Estimation on water-use amount of ecosystem and environment equates,

$$WU_{i,63} = Greenland_{i,63} \times Intensity_{i,63} + Sanitarea_{i,63} \times Intensity'_{i,63} \quad (13)$$

where $WU_{i,63}$ is water withdrawal of prefecture i for ecosystem and environment,

$Greenland_{i,63}$ is area of green land of prefecture i (represented by urban green land areas at this stage), and $Intensity_{i,63}$ is irrigation volume per green-land area in urban areas of prefecture i .

$Sanitarea_{i,63}$ is environmental sanitation areas of prefecture i , and $Intensity'_{i,63}$ is water withdrawal per unit of prefecture i . Irrigation water withdrawal per green-land, and water withdrawal per environment and sanitation area, were from the Bulletin of 1st Water Resources Census (i. e., 2nd Water Resources Census of Shanghai by the Shanghai Bureau of Statistics and Water Authority). Environmental sanitation area was taken from statistical yearbooks for each city. Green land area was from China City Statistical Yearbook. Detailed meanings of abbreviations are also shown in Figure 8 and Table 1.

Besides, in the subsector module, for farming subdivisions, we calculated proportions of irrigation for cultivation of five main crops in 343 prefectures from Zhou et al. (2020)³⁷. Water withdrawal per irrigated area by crop was calculated based on the irrigated area data from Zhou et al. (2020).

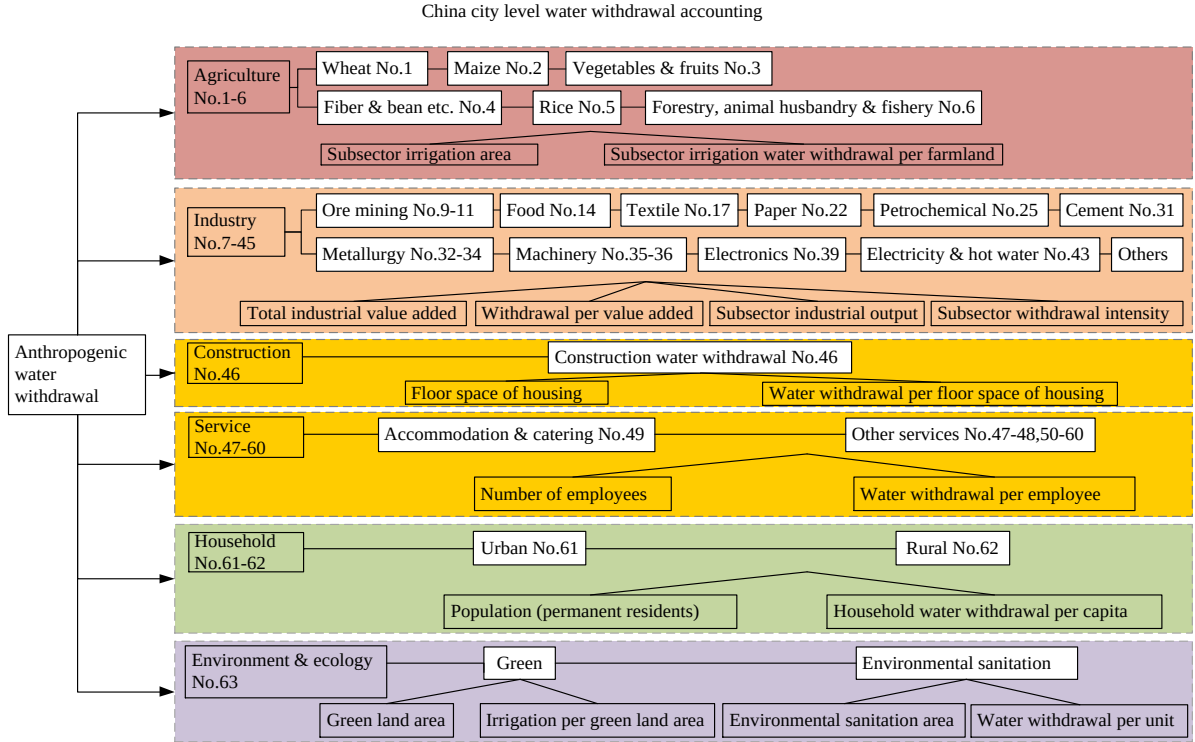


Fig.8. Indicators for prefecture-level and subsector water-withdrawal accounting and classifications. It is based on selections of 16 driving forces for water withdrawal datasets.

Overall, approximately two fifths of 343 prefectures do not collect or develop water data statistics, i.e., categorized into the *Case 2*. For data of the other three fifths of prefectures, there are only total numbers of six types provided, i. e., categorized into the *Case 1*. Concretely, prefectures from Jiangsu, Zhejiang, Guangdong, Anhui, Hainan, Heilongjiang, Tibet, and Jilin were categorized as *Case 2*. The remaining prefectures were in *Case 1*. For methodological validation, please refer to detailed discussions in references ^{29,30,38}, and Turner et al. (2010) ²⁴.

Table 1 Driving-force indicators and their sources.

Table 1 Driving force indicators and their sources.				
Agriculture		Irrigation area	○	○ Province statistical yearbook
		Irrigation water withdrawal per mu of farmland	√	
Industry		Total industrial value-added	○/△	△ City statistical yearbook
		Water withdrawal per industrial value-added	√	
		Subsector industrial output	△	○/△ Province or city statistical yearbook or internet search
		Disaggregated water withdrawal intensity of each sector	※	
Construction		Floor space of housing	○	√ Water Resource Bulletins
		Water withdrawal per floor space of housing	X	
Services	Accommodation & catering	Number of employees in accommodation & catering	U	※ National Pollution Source Census and Regular Reporting Systems of the Ministry of Ecology and Environment
		Water withdrawal per employee in accommodation & catering	X	
	Other services	Number of employees	U	
		Water withdrawal per employee in other services	X	
Household	Rural	Rural population (permanent residents)	○	X the Bulletin of 1 st Water Resources Census (i. e., 2 nd Water Resources Census of Shanghai by the Shanghai Bureau of Statistics and Water Authority)
		Household water withdrawal per capita in rural areas	○/△	
	Urban	Urban population (permanent residents)	○	
		Household water withdrawal per capita in urban areas	○/△	
Ecosystem & environment		Area of Green land	U	U China City Statistical Yearbook
		Irrigation volume per area of green land in urban areas	X	
		Environmental sanitation area	△	
		Water withdrawal per unit	X	

Note: this is in furtherance to a previous publication³⁸.

Overall, our methods have been the most up-to-date accounting approaches so far. In particular, She et al. (2024) has regarded our methodology as useful: the study pointed out the unavailability of detailed water-use data at the subsector level, then stressed that, our methodology should be used to construct water-use accounts to severely robust its conclusions. This study considered its numerical results might be uncertain, due to assumptions made in the absence of prefecture-level water-use data⁷. Besides, our methodology is preferable to simplistic ‘monetary amount and price’ methods^{7,35}.

ii.) About the cost, as well as a systematic scenario expansion, we fully agree with you, because we think such cost analyses would genuinely improve this manuscript to be more comprehensive for decision-making. We compiled and supplemented some information on relevant economic cost. We wish it would be useful. We summarized seven kinds of mainstream and emerging techniques, i.e., six for irrigation (applicable to cultivation of wheat and maize etc.) and one for power-generation, as listed in R. Table 3. In this process, on-site visits were used to gather data. We find drip irrigation, for example, requires an initial investment of approximately \$2,200 per hectare and an annual maintenance cost of \$880. Large-scale adoption will likely depend on government subsidies, as high upfront costs may deter farmers.

R. Table 3 A scheme of seven mainstream and emerging water-saving techniques.

Sub-sector	Type	Measure or technique	Definition	Saving potential (%)	Current status or area	Feasibility		Prospect (↑↓)
						Cost, expenses for applications (\$)	Optimal water use amount (m ³)	
Agricultural irrigation	Micro-irrigation	Drip irrigation ^{15,40-42} ; Subsurface drip (SSD); surface drip (SD)	40% in soil surface wetted ^{15,16}	50-80 [†]	Small area and expansion	Fixed investment: 2,200 per ha, plus 880 per ha per year for mulch etc. consumable*	1,800 per ha (winter wheat) ⁴³ , 5,907 (corn)	Continuous expansion, to be leading, with fertilizer & plastic mulch techniques ^{15,16,40}
		Sprinkler irrigation	60% in soil surface wetted ^{15,16}	30-60	485 k ha for wheat [*]	Cost higher than benefit; 75% irrigation time shortened.	N.A.	To decline in cultivated area
		Bubble irrigation	N.A.	30	N.A.	N.A.	N.A.	N.A.
	Irrigation through pipelines	Low pressure pipelines	N.A.	15-30	11,517 k ha	N.A.	N.A.	N.A.
	Canal seepage control	Canal leakage control	N.A.	15-30	N.A.	N.A.	N.A.	N.A.
	Furrow & canal	Canal & furrow	80% ^{15,16} , usually based on a constant interval ⁴⁴ , without moisture monitor	15	Dominating in China ^{15,16}	N.A.	6,822 per ha (corn)	To sharply decrease in cultivated area
Industrial power generation	Water recirculation cooling	Wet towers	Transition from single-pass to recirculating-cooling	97%, from 168 liters to 5 of water abstraction per kwh ⁴⁵	Less than 10% thermal plants [#]	Total generation costs at 0.05 per kwh ^{46,47}	159 million for electricity & hot water supply	Substantial room to reduce ⁴⁸

Note: 1) [†] there is no substantial gap in water-saving potential between SSD and SD. Data are from Tianjin city in 2023⁴². 2) * for Zhangbei county in Hebei province, north China. 3) ^{*} data is in 2014. 4) [#] for Suzhou city, in Jiangsu province, east China. 5) N.A. denotes none-available data at the current stage. 6) Full names of sector are indicated by ‘&’ for short, throughout the paper.

In 2014, micro-irrigation area of cultivated wheat of China is 952 k ha. In 2021, proportion of China's micro-irrigation area in total agricultural irrigation area is 16.89%, according to the International Commission on Irrigation and Drainage (ICID) database⁴⁹. Proportion of micro-irrigation area (11,816 k ha) in water-saving irrigation area (37,796 k ha) is 31%. Towards future, we predict that on one side, large-scale applications of these water-saving techniques are booming globally, especially in developing countries^{15,16}; On the other side, such applications should continue to rely on fiscal subsidies and promotions from government, because added inputs usually decrease profits of farmers⁵³. Currently, farmers alone are unwilling to adopt such water-saving techniques.

Yet, to verify robustly a financial feasibility of adopting such techniques is a complex or systematic engineering work^{31,50,51}.

i.) Some cost analyses are mainly in engineering and fined projects, such as designs and plans on new districts and industrial parks¹⁹. Usually these cost analyses are based on specialized economics models, including marginal abatement cost curve to estimate economic cost per water saved, which require large workload⁵². For instance, Boyer et al. (2016) considered how local utility would not fail to profit through scenario analyses, at diverse water tax and price in future⁵³. Similarly, for agriculture, this kind of work requires both field-crop research and simulations: Principles of agriculture engineering usually determine water use amount based on characteristics of crops and potential water requirements during growth period⁵⁰. Law of potential water requirements is subject to types of irrigation engineering and flexible periods^{50,54,55}, i.e., four stages of irrigation distinguishing reviving, jointing, heading, and grain-filling, rather than based on a constant irrigation interval as flood irrigation⁴⁴. Besides, mulch-drip irrigation system is also usually combined with fertilizer management^{15,16,40}.

ii.) About the techniques, given that improving water-use efficiency is a slow and difficult process⁵⁶, at this stage, we find difficulty in obtaining or mapping such fined or detailed technical data as for each prefecture or sector³¹, i.e., specific techniques, accurate water-use amount for industrial output (\$) or agricultural crop (or irrigated area, in m²), water-saving coefficient and cost⁷. Concretely, 1) we could find techniques at the product and equipment levels, as Xu et al. (2024)⁵⁷ did, to cut down package-related water use. Other studies are through material flow and metabolism analyses⁹, agent-based models⁷ and life cycle analyses⁵⁷. 2) We could also find techniques typically within a certain sector⁷. In this regard, most research focus on cooling systems within the power-generation sector, or iron & steel sector⁵². Yet we find challenge in matching technique information.

This challenge stems from existing water policies³¹, in particular control on water-use price. For example, in coal-fired and power-generation sector of China, there is no substantial difference on generation costs from the one-through cooling techniques to circulation cooling techniques. Moreover, water-related cost merely occupies a small proportion in the total generation costs at 0.05 US\$ per kwh^{46,47}. The water-related cost ranks after fuel cost (1st), investment depreciation cost (2nd), and operating and maintenance cost (3rd), as a previous study find that at current water prices, commercial companies are unlikely to adopt water-conservation measures⁵³.

iii.) Our study is based on a methodology developed and national census data. Consequently, it could be constrained by the limitations of our datasets. And we acknowledge this is a limitation of this study at the current stage. In our future research, we could expect a breakthrough to develop technologically driven pathways through individual plants along with their technical characteristics, including processing routes and operating details (status, age, operation-years etc.)³¹. At this stage, we may regard concrete analyses on the economic costs and benefits as a bit beyond scopes and purposes of this manuscript. We would consider to expand this part, i.e., pay-off accounting, in our next research⁷. Concretely, because in this study, we have analyzed

environmental benefits of water saving, i.e., its impacts on water scarcity, for our next step, we would explore interlinked environmental-economic-social effects of water saving³¹. For example, climatic co-benefits of water saving include consequent energy-consumption and carbon emission^{9,58}, as a research in Tucson showing that a 20% decrease in water demand across all sources directly equals a 20% decrease in energy consumed for water^{9,46} (here energy consumption of water use is mainly considered for water heating on industrial uses and circulation-cooling water systems during industrial processes). Besides, at the corporate level, water efficiency improvements do not necessarily lead to increased operational costs. In this regard, water saving would also bring economic benefits. In sum, water-saving disruption and cost are worthy of further exploration. Future research will explore financial feasibility in greater detail through case studies, examining payback periods and economic impacts.

- Comment 11: While the authors have conducted research competently, the manuscript reads like a technical report.

– Response 11: Thank you for reading through our manuscript. We have deleted the outdated and irrelevant contents. In addition, we also make it concise based on the added references.

- Comment 12: In particular, the discussion section could be improved by engaging with relevant literature to substantiate the authors' statement. The authors cite a reference to environmental regulation by development stage (in line 191) but do not discuss how regulations differ by region. Do more affluent big cities (mostly in coastal cities) have more stringent regulations compared to less affluent, relatively small inland cities? Why are water-intensive industries located in certain cities? What are the characteristics of these cities? How does industrial restructuring relate to water use intensities across cities? A political economy or political ecology perspective could help substantiate the authors' statements.

– Response 12: Thank you for raising these detailed questions, as well as instructions. We appreciate your expertise in this field. We followed your questions and looked for some detailed evidence from the literatures. To be brief, affluent coastal cities generally implement stricter water-use policies, while smaller inland cities adopt more lenient regulations to promote economic growth. These regulatory differences shape the distribution of water-intensive industries, which tend to cluster in inland areas where policies are more relaxed.

i.) With regard to the loose environmental-regulation or enforcement in different stages or periods of development^{18,59}, early studies Zhou et al. (2013) and Kuang et al. (2018) stated ecological regulations at detailed and different stages of an urban system⁹, including the famous Xiong'an New Area of Hebei province of China⁶⁰. We also referred to Zhang et al. (2020)⁶¹ and Zhou et al. (2020)³⁷. For different regions, Wang et al. (2019) and Wang et al. (2023) investigated distribution of irrigation regulations and techniques correspondingly^{15,16}. We also referred to Zhang et al. (2022)⁵⁸. These literatures show that inland regions are usually water-scarce but tend to loosen their regulations for economic development, due to crop cultivation and lower wealth per-capita. This could also result in relatively more water-intensive crops and heavy-industries being located in these inland prefectures. Specifically, loose regulations are in terms of evaluation for policies and plans, which are usually conducted or reflected by the inland authorities or local governments themselves.

Such differences from loose to stringent regulations bring industrial transfer and market restriction policy: introduction of technology and industries, and sales of products, should be based on how much water a local prefecture has, and whether their water efficiency performance could meet local standards, otherwise it should only be eliminated or transferred to somewhere with looser restriction^{61–63}. For example, some industries in Beijing have already been relocated into its surrounding provinces, in accordance with geographical endowment of water resources. This policy could be matched with water label policy.

ii.) About structure change and water-use efficiency among cities, we found some high-intensity water withdrawers were mostly in small and developing prefectures, such as Nanchong, Zhuzhou and Fuzhou (in Jiangxi province) in industrial-related sectors; Zhoukou, Linyi and Fuyang in agricultural sectors. In contrast, other cities had more low-intensity sub-sectors, such as Shenzhen, Tongliao, Rizhao and Fushun in industrial-related sectors; Kelamayi in agricultural sectors. At the same time, we also found these high-intensity prefectures being constrained by high (and extreme) water scarcity. They produced with advanced water-saving technology, and built a water-saving economy⁶⁴. For example, although water withdrawal-to-availability ratio in Tongliao was 80%, meaning high water-stress, nevertheless, sufficient economy growth (7.8% GDP growth rate, higher than average) was supported due to advanced water-saving irrigation technology and industrial structure around 2016⁶⁵. Due to city transition, conventional industrial and northeastern prefectures, such as Harbin, Daqing and Changchun, were less water-intensive than those southern prefectures, e. G., Ningbo, Shaoyang, Jingdezhen, Jiujiang, and Baoshan.

R. Table 4 An index of top-5 industrial-related sectors of high water-withdrawal intensity and their representative prefectures.

High intensity sectors (top 5)	Average intensity (m ³ per k \$)	Standard deviation	Range (m ³ per k \$)	Number of sector- prefecture combinations	Representative prefectures (intensity)	
					Top 5 (m ³ per k \$)	Bottom 5 (m ³ per k \$)
Electric power, steam & hot water	29.3	5.5	[0, 141.8]	254	Nanjing (139.1), Luohe (91.4), Binzhou (75.7), Nanchong (124.9), Neijiang (117.3);	Leshan (1.09), Zhenjiang (1.02), Wuwei (1.09), Ningde (0.41), Ganzhou (0.07);
Paper products	25.4	8.4	[0, 196.3]	215	Guilin (179.3), Handan (173.84), Hengyang (159.53), Taiyuan (164.98), Xi'an (171.12);	Tongliao (1.50), Shenzhen (0.14), Benxi (0.07), Beijing (1.16), Ankang (0.34);
Mining & processing of ferrous metal ores	23.7	5.7	[0, 140.4]	128	Nanjing (132.3), Zhangzhou (135.7), Fuzhou (94.8, Jiangxi), Zhuzhou (92.0), Quanzhou (85.2);	Rizhao (0.01), Mianyang (0.34), Wuhan (0.01), Liuzhou (0.02), Linyi (0.07);
Mining & processing of nonmetal ores	20.8	7.9	[0, 183.4]	117	Changde (149.3), Fuxin (93.4), Wuwei (83.17), Zhuzhou (102.94), Anqing (89.31);	Suizhou (0.0682), Yangjiang (0.0682), Xinyang (0.0682), Xiangtan (0.0682), Lu'an (0.0205);
Mining & processing of nonferrous metal ores	15.4	3.7	[0, 91.4]	124	Fuzhou (90.67, Jiangxi), Ganzhou (82.59), Suizhou (81.13), Wuzhou (72.26), Lishui (72.26);	Akesu (1.02), Fushun (0.82), Suzhou (0.14), Shaoxing (1.09), Linfen (0.27)

Note: industrial output was used to estimate water withdrawal intensity.

R. Table 5 shows water withdrawal index and other socioeconomic characteristics of 18 representative prefectures. Some prefectures, such as Hengshui, Yantai, and Qingdao, have less water withdrawal per capita and lower water withdrawal intensity than others. There are two possible reasons: 1) their production structures are relatively less water-consumptive⁶⁶; 2) these areas have advanced water-conservation technology. For example, Hengshui is aimed to become a pilot prefecture for water conservation, and it has broadly applied drip and sprinkler irrigation in modern agriculture-parks⁶⁷. There are two above-100,000-metric-ton desalination factories in Qingdao, which represent the cutting-edge technology of China⁶⁸. In addition, mulch planting and the integration of water into fertilizer have also been developed in Qingdao and Yantai cities.

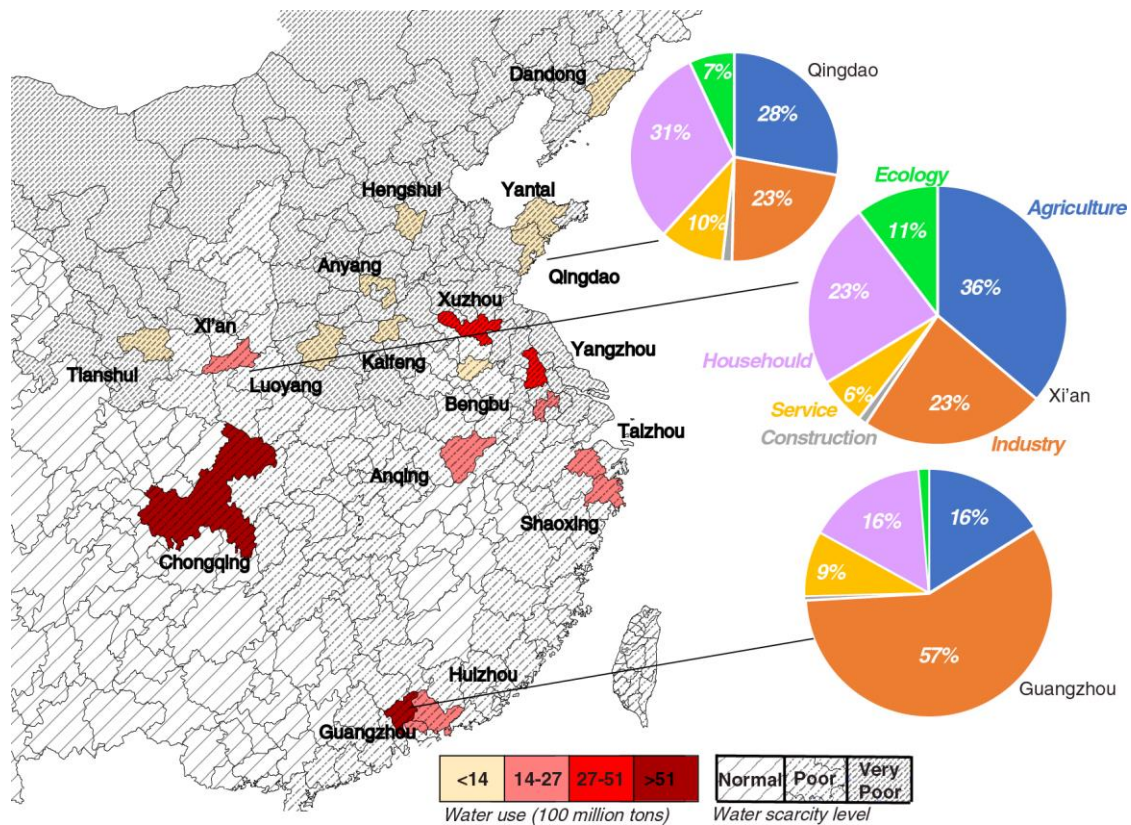
R. Table 5 Water withdrawal and socioeconomic index of 18 representative prefectures.

Prefecture	Province	Representative economic zone	Region	Water scarcity assessment	Ww (10 ⁶ m ³ yr ⁻¹)	Water intensity (m ³ per k \$)	GDP per capita (\$)	Population (10 ³)	Ww capita ⁻¹ yr ⁻¹ (m ³)	Household Ww capita ⁻¹ yr ⁻¹ (m ³)
Hengshui	Hebei	Jing-Jin-Ji	North	Very Poor	301	17	4040	4520	67	6
Yantai	Shandong	Central Bohai Bay			869	9	13492	6530	133	21
Qingdao					876	6	15038	7820	112	35
Dandong	Liaoning				979	67	5992	2390	410	38
Tianshui	Gansu	Western zone	West	Normal	371	45	2487	3310	112	17
Chongqing*	Chongqing				9514	42	7675	33740	282	40
Xi'an*	Shaanxi				1820	21	9819	8150	223	52
Huizhou	Guangdong	Pearl River Delta	South	Poor	2059	45	9715	3530	584	97
Guangzhou*					6614	25	19977	8480	780	122
Shaoxing	Zhejiang	Yangtze River Delta	East		1962	30	13202	4430	443	57
Taizhou					1886	36	8642	5970	316	45
Xuzhou	Jiangsu				5115	65	9023	10260	498	17
Yangzhou					3962	67	13150	4610	859	60
Kaifeng	Henan	Central zone	Center	Very Poor	1316	56	5182	5510	239	21
Luoyang					1413	28	7582	6980	202	30
Anyang					1436	52	5402	6140	234	32
Anqing	Anhui			Poor	2702	130	4562	6220	434	35
Bengbu					1242	67	5613	3740	332	34
Total	11	6	5	3	18	12	3	18	18	18

Note: Ww is short for water withdrawal. * indicates a capital-level prefecture. Water withdrawal is from water resources bulletins. GDP per capita and population are from statistical yearbook of each prefecture. Water intensity, water withdrawal per capita per year, and household water withdrawal per capita per yr, are from our estimation. For simplicity, *Normal* water scarcity levels indicate that there is neither quantity- nor quality-induced scarcity in these cities, *Poor* indicates there is only quality-induced water scarcity, while *Very Poor* indicates both quantity- and quality-induced water scarcity. For more information, refer to the method developed by Liu et al. (2017) based on Zeng et al. (2013)^{69,70}.

Last but not least, we also find industry water withdrawals in some prefectures have dominated the water-use structure. In Xi'an, Shaoxing, Taizhou, Luoyang, and Chongqing, the shares of agricultural water withdrawal are less than 50%. Industrial water withdrawal accounts for a large percentage in the water-use structure of some prefectures. Specifically, at the prefecture level, industrial water withdrawal accounts for a mean 25% in overall production water-use. This proportion ranges from 0.24% in Hotan (in northwest China), to over-35% in Shanghai (east), Chongqing (southwest), Nanjing (mid-east) and Fuzhou (south-east), and to 94.83% in Baishan (northeast). Industrial water withdrawals are ranked the first in 17% of prefectures, and the first-two places in 97% of prefectures among productive water withdrawals. Industrial water withdrawal is mainly driven by large production scales in some prefectures. For example, industrial output above designated-size in Dongguan is the largest and reaches 19 million US\$, almost three times of the average of prefectures. This large output is mainly constituted of communication, electronic machinery & equipment, and electric power, steam & hot water ⁷¹, in the structure of statistical output according to bureau of statistics.

iii.) Concerning water-use structure and industrial scenario analyses, R. Figure 1 depicts three representative water-use structure. For agriculture water withdrawal proportions, Guangzhou is the smallest; Xi'an is the largest; and Qingdao is moderate (balance). Total water use structure is 'balanced' in a number of prefectures (that is, water use structure in a prefecture has different parts in an average proportion), nevertheless, this could not be a good sign, considering these prefectures have supplied maximum available water amount as prefectures grew, which should degrade life standards and hinder sustainable economic development in future.



R. Figure 1 Three representative structures of water-use at the prefecture level. This is in furtherance to our previous paper³⁸.

There are also some other detailed and economic simulations through multi-objective optimization and decision-making models inter-cities^{58,72}. For example, Zhang et al. (2020) applied an Input-Output model to simulate and demonstrate that water-saving techniques are readily available and conducive in the process of industrial restructuring⁶¹.

iv.) About a political-economy or political-ecology perspective, referred to the *National Office for Water Saving* of the Ministry of Water Resources of China, we find that political promotions are compulsorily required to put weight on water-saving performance to assess officials' achievements. In particular, some collectors are fear to reveal water-use data: in China, some officials with responsibility for water use could feel pressure to unveil water-use data to the public because these data are included in the performance evaluation system for political promotion, and they care about their own achievements. For details, see in references^{73,74}. In this regard, our data would increase transparency.

- Comment 13: The maps could be improved. In Figure 1, the authors showed specific cities to make their points. However, they seem to appear islands in either ocean or other countries. I suggest that the authors remove these isolated polygons. Additionally, I am confused about blurry islands shown in the northeast coast. I do not think such islands exist in the ocean. Please remove them. A scale bar should be included at least in one of the maps.

– Response 13: Thanks, we have removed those blurry islands, and supplemented a scale bar.

Minor comments

- Comment 14: Line 111. Insert comma after “Thus”.

– Response 14: Thanks, we have revised these throughout our manuscript.

- Comment 15: Line 139. Insert comma before “including”.

– Response 15: Thanks, we have revised it.

- Comment 16: Line 168. Change “9” to nine.

– Response 16: Thanks, we have revised it.

- Comment 17: Line 198. Insert comma before “including”.

– Response 17: Thanks, we have revised it.

- Comment 18: Line 241. “according to ref”. What reference are you referring to?

– Response 18: Thanks, we have rewritten it.

- Comment 19: Line 261. Any reference to support your statement?

– Response 19: Thanks, we have supplemented references as required.

- Comment 20: Line 280. “Insert apostrophe after “years”.

– Response 20: Thank you for your detailed review, and we have revised it. We read further to double-check these problems.

At last, we appreciate your criticisms. These help us extend our cross-disciplinary horizon and see more possibilities.

Reviewer #2 (Remarks to the Author):

- **Comment 21:** The authors have compiled and analyzed a detailed water use dataset for China for 2015. The dataset covers water use for agricultural and industrial purposes at the “city” level, comprising 343 prefectures, with categorization of water use into 6 groups: agriculture, energy production, manufacturing (3 levels), and services. Water use figures are presented in nation-wide maps as well as a series of charts that analyze water use efficiency. Water scarcity forms another key focus of the results and analysis, both for 2015 and for a set of scenarios for 2030-2060. Overall, the paper is well-written and novel, and should be of interest to the scientific community. I recommend some minor revisions and clarifications below.

– Response 21: Thanks for your comments and considerations. To estimate these data, we have constructed a specialized accounting methodology, which have been supplemented in detail in this round of revisions. We wish to provide a solid basis in this regard to revise and reduce problems for this manuscript.

Specific comments:

- **Comment 22:** • Line 81: The term “city” is used throughout the paper to refer to sub-provincial “prefectures”. Given the size of some of the “cities” in western China (Fig. 1), and their agricultural nature in some cases, a different term would probably be better. Prefecture would probably be fine, for example.

– Response 22: Thanks, we fully agree with you. We have revised these. ‘Prefecture’ is indeed accurate, and has been mainly used in this manuscript. ‘City’ could be in a plain language and easy to understand.

- **Comment 23:** • Line 92: Please define the “sector” and sub-sector” terms clearly, and provide more detail. According to the given definition, a “sector” is an economic classification. However, a later line (253) refers to agricultural and industrial sub-sectors, suggesting that agriculture and industry are also “sectors”. Other sections of the paper refer to “sub-sectors”, which are not defined (e.g. Line 124 and line 261). Please also state the total number of sectors represented in the analysis.

– Response 23: Thank you for your detailed comments. We fully agree with the issue you have pointed out. And we have supplemented this definition.

A ‘sector’ denotes at the national level, 63 broad classifications, as is shown in the Supplementary Table 1. Breaking down each national sector, a ‘sub-sector’ means those composed of a fewer number of companies and distributed inner individual prefectures.

In this study, we have realized disaggregated partitions on the national and broad sectors. In total, we have 63 national-sectors, including five agricultural sectors and 39 industrial sectors, and obtain $5\text{-sectors} \times 343\text{-prefectures}=1,715$ agricultural sub-sectors and $39\text{-sectors} \times 343\text{-prefectures}=13,377$ industrial sub-sectors for all 343 prefectures, for emphasized analyses on agriculture and industry water-use. For example, we investigated water use per industrial output in each sub-sector of prefecture, and its corresponding level in the national-sector.

- **Comment 24:** • Line 137: How can the study be a “policy tool”? Please revise the wording.

– Response 24: Thank you for your comments. We have revised this. ‘The study could be useful for individual prefectures and sectors to look up detailed water use and efficiency information.’

- **Comment 25:** • Data collection is described in the Methods section, and comments will follow below. However, line 144 refers to “point-source surveys” that could be described

in greater detail either in the Methods or the Supplemental Materials. I am curious about how water use data are collected, presented, and made available in China.

– Response 25: Thank you for your detailed comments and instructions. We have supplemented an overall description on the background information in detail. We may also wish to supplement some clarifications on our methodology.

For all the data presented in this study, we need to develop a general framework, to realize estimation on detailed and subsector water use. Unfortunately, for the time being, few published data on water-use exist, although China's water issues are of international interest. As of 2024, as a foundation for water accounting, full monitoring or metering on agricultural water-use remains inadequate and needs to be supplemented, according to the National Development and Reform Commission of China, etc.^{22,34}. Compared to developed countries, such as Australia, America and France^{4,75,76}, water accounting in China has already fallen behind. Disaggregated and subsector water-withdrawal accounting is not readily available for China. Not all prefectures in China are able to account for water as 'routine' management activities, as in Australia, America and France^{4,75,76} etc. Approximately two fifths of 343 prefectures do not collect or develop water data statistics. For data of the other three fifths of prefectures, there are only total numbers of six types provided, with differences in terms of statistical caliber etc. New accounting methodology was needed to develop, which should be suitable for new cases, according to specific statistical conditions of different prefectures and sectors, as well as China's own actual state. This is quite different from developed countries. Water withdrawal statistics in China are patchy, and water data across all sectors at the prefecture level appear to be relatively insufficient. Different from past publications, this paper is aimed to open and publicize these water-use data. We wish to continuously generate these data and develop professional datasets, i.e., the Dataset on Water Use of China at the Sub-sector level (DWUCS).

In our methodology of DWUCS, core and primary data are from national pollution source census and regular reporting systems of the Ministry of Ecology and Environment. In the census and survey, we investigated 161,598 companies (approximately 42% of all above designated-size companies of China; above designated-size company refers to those with annual business revenue over 2.93 million US\$³⁶; exchange rate at US\$1 = ¥6.8174). Apart from carbon emissions, water-withdrawal information collection was conducted, and industrial economic-output data were coupled with water-withdrawal data of companies. Then these data were subsequently aggregated according to sub-sectors to calculate the intensities, i.e., water withdrawal intensities for individual sub-sectors in each prefecture across 13,377 industrial sub-sectors for all 343 prefecture-level cities.

- Comment 26: • Line 150: Efficiency figures like these are not contextualized. Please provide some measure of how such values compare to OECD, US, or world averages? (Figure 5 provides some context, but it is very general).

– Response 26: Thanks for your comments. We fully agree with you, and have revised to specify this part.

Average water-withdrawal per industrial value-added at the prefecture level of China is 50 m³ per k-US\$. From a global perspective, this still has a gap compared with the worldwide countries with the most-efficient water-withdrawal at 3.43 m³ per k-US\$ industrial value-added in 2022, according to data from the China Institute of Water Resources and Hydropower Research.

Basically, China's water-withdrawal efficiency is comparable to that of the middle-to-high income countries. On average, water withdrawal per industrial value-added of the US is not the most-advanced, at 34-50 m³ per k-US\$ among different industrial-sectors. If we include the US data, average water withdrawal per k-US\$ (industrial value-added) of the high-income

countries would increase from 21.07 m³ to 33.81 m³ ^{77–79}.

We would like to explore this part in our future study.

- Comment 27: • Page 6 of 36: Values are provided for industrial and agricultural water use, but not for residential use. Is it possible to provide residential or municipal values?

– Response 27: Thanks for your questions. Yes, we have accounted residential water-use. We provide values also in our attached files in the Manuscript Tracking System of CEE. In total, we have 63 sectors, mainly including five agricultural sectors and 39 industrial sectors, and obtain 5-sectors × 343-prefectures=1,715 agricultural sub-sectors and 39-sectors × 343-prefectures=13,377 industrial sub-sectors for all 343 prefectures.

Apart from background in the Introduction section of the main text, other reasons for emphasizing analyses on agriculture and industry water-use are that: 1) average share of agricultural irrigation occupies approximately 60%. 2) industrial water withdrawals are ranked the first in 17% of prefectures, and the first-two places in 97% of prefectures among productive water withdrawals. Please also refer to our *Scientific Data* paper ^{29,30} for more details.

Conventional statistics on the municipal water-use include those for construction, service, and ecosystem and environmental preservation. In China's statistics, a 'public water withdrawal in urban areas' is defined as the sum of water withdrawal for construction and all the services. This definition of water withdrawal is a statistical feature that is different from other energy, resource or economic statistics.

In this study, due to word and length considerations, we focus on the water use for production in agriculture and industry at this stage. We would like to explore this part in our future study.

- Comment 28: • Lines 157 and 164: There are some very small values of water use reported here. Are they reliable? What do they say about the quality of data available?

– Response 28: Thank you for your important questions. We have supplemented to perform sensitivity analyses as required. For sensitivity analyses and validations on methods, we referred to and used procedures in previous studies^{24,25}. Overall, for *Case 2* on estimation for prefectures without water withdrawal statistics, water withdrawal efficiency was a key uncertainty. We conducted sensitivity analyses by replacing these efficiency data with regional efficiency. The regional efficiency data were from provincial and regional Water Resources Bulletins.

Concretely, we estimate the sensitivity of water withdrawal by agriculture, industry, and services for prefectures, by replacing the specific intensity value with regional, provincial or national magnitudes based on data availability. We take the prefectures of Anhui, Jiangsu, and Zhejiang as examples, because their Water Resources Bulletin did not provide water withdrawal for the six types for some of their prefectures.

For agricultural water withdrawal, one assumption is applied for prefectures without statistical information: If there is no available irrigation water-withdrawal per mu for farmland, the water withdrawal intensity for the agriculture sector would be the same. We conduct a sensitivity analysis by replacing the intensity with the regional or provincial values, the results of which are shown below:

R. Table 6 Sensitivity analysis of agricultural water withdrawal

Prefecture	Original agricultural water withdrawal (10^6 m ³)	Irrigation area (10^3 hectare)	Irrigation water withdrawal (m^3) per mu for farmland	Replaced agricultural withdrawal for sensitivity test (10^6 m ³)	Percentage difference (%)
Hefei	1503	458	282	1295	13.9
Bengbu	778	237	282	670	13.9
Huaibei	468	143	282	403	13.9
Tongling	268	82	282	231	13.9
Huangshan	168	51	282	145	13.9
Suzhou	1384	422	282	1192	13.9
Xuancheng	658	201	282	567	13.9
Wuxi	610	173	461	711	-14.3
Xuzhou	4086	1161	389	4024	1.6
Changzhou	756	215	461	882	-14.3
Nantong	2942	836	389	2898	1.5
Lianyungang	2231	634	389	2197	1.6
Huai'an	2801	796	389	2758	1.6
Zhenjiang	831	236	389	818	1.5
Taizhou	2046	581	389	2015	1.5

Note: The percentage difference is calculated as (column2- column5)÷column2*100%. + and - are determined by whether actual intensity of selected sample is higher than the provincial average or not in their respective sector. Table 6 is for agriculture and Table 7 is for industry. Table 6 and Table 7 are somehow separated or independent from each other.

Although the largest differences between *Agricultural water withdrawal'* (estimated with the replaced agricultural water withdrawal intensity) and our original estimation appeared in Wuxi and Changzhou (-14.3%) in R. Table 6, the average variation of the absolute value was 9.0%. This result indicates that there are no substantial differences, and our method provides a credible estimation of agricultural water withdrawal.

R. Table 7 Sensitivity analysis of industrial water withdrawal

Prefecture	Original industrial water withdrawal (10^6 m ³)	Industrial value added (10^9 \$)	Industrial water withdrawal (m^3) per k \$ value-added	Replaced industrial withdrawal for sensitivity test (10^6 m ³)	Percentage difference (%)
Hefei	964	33	30.7	1011	-4.8
Bengbu	291	10	30.7	305	-4.8
Huaibei	214	7	30.7	225	-4.8
Tongling	185	6	30.7	194	-4.8
Huangshan	54	2	30.7	57	-4.8
Suzhou	157	5	30.7	165	-4.8
Xuancheng	176	6	30.7	184	-4.8
Wuxi	520	43	10.2	502	3.7
Xuzhou	477	40	12.3	552	-13.5
Changzhou	461	38	10.2	444	3.7
Nantong	511	43	9.5	467	9.5
Lianyungang	204	17	12.3	236	-13.5

Huai'an	261	22	12.3	302	-13.5
Zhenjiang	358	30	9.5	327	9.5
Taizhou	434	36	9.5	397	9.5

Note: For prefectures in Anhui, we could obtain only the industrial value-added for the above-designated-sized enterprises.

For the industrial water withdrawal estimation, although the largest differences between *Industrial water withdrawal'* (estimated with the replaced water withdrawal intensity) and our original estimation appeared in Xuzhou, Lianyungang, and Huai'an (-13.5%) in R. Table 7, the average variation in the absolute value was 7.3%. This result indicates that there is relatively low sensitivity, and the method provides a credible estimation of industrial water withdrawal. Moreover, the prefectures were the same as those selected for the validation of agricultural water withdrawal, which also supports the robustness of our method.

Similarly, for services, we assumed that the water withdrawal per employee would be equal within a prefecture (for prefectures with statistical information) or among prefectures (for those without). We estimated the uncertainty of other services using water withdrawal per employee at the national level from the prefectures with statistical information. The list of prefectures used is provided in Appendix. We observed that the average variation was 8.0%. This result indicates that there are no large differences, and the method provides an accurate and credible estimation on service water withdrawal. In fact, similar proportions were also used in the estimations of the *China Institute of Water Resources and Hydropower Research* ^{26–28}.

Finally, given that China did not officially report statistics on environmental sanitation areas at this stage, we omitted the validation of environmental water withdrawal. Nevertheless, this would be possible when such data are available, considering that many prefectures are beginning to explore how to estimate their environmental-sanitation areas.

Besides, we deleted some uncertain magnitudes, and we have double-checked the other ones to make sure they are all from the census.

- Comment 29: • Line 166: Please state briefly here which measure of water scarcity is used. The explanation can be in the Supplemental Materials, but at least the name should be here.

– Response 29: Thank you for your kind suggestion, and we have supplemented as you instructed. The water scarcity here is Criticality-Ratio: ‘In terms of measuring water scarcity, the Falkenmark indicator is a well-known measurement of water shortage, with per capita renewable water resources ⁸⁰, nevertheless, it does not reflect the environmental flow requirement ^{70,81}. The criticality ratio (%) is a classical indicator of blue water and quantitative scarcity ^{82,83}, connecting anthropogenic water withdrawal with natural water quantity, and taking into consideration both environmental flow ^{84,85} and natural biodiversity ⁸⁶.

The criticality ratio was determined by dividing total freshwater withdrawal (Fig. 1c) by water availability (Supplementary Fig. 2a) for each prefecture annually ^{87–89}, i.e.,

$$Criticality_ratio_i = \frac{\sum_{k=1}^{63} (Water_use_{i,k})}{Water_availability_i}$$

where i represents a prefecture; k stands for a sub-sector of prefecture i ; $\sum_{k=1}^{63} (Water_use_{i,k})$ is the total amount from farming, forestry, animal husbandry, fisheries, industry, construction,

service, household, and ecosystem and environmental preservation (for more descriptions, please refer to Supplementary Table 1). *Water_availability_i* is collated from water resources bulletins at the province and city levels, referred to previous studies^{39,90–92}.

Empirically, above-40% is regarded as high water-scarcity status^{93–95}, and over 100% as extreme water-scarcity, signifying that annual water withdrawal exceeds renewable water resources⁹⁶. This indicates unsustainable development: local unrenovable water resources would decline, the ecological water-cycle would destruct⁹⁷; urgent water transfer would be required. The higher the ratio is, the more stress is placed on available water resources from withdrawal, and the greater the occurrence of water scarcity^{93,98}. For example, in Supplementary Fig. 2b, the median water criticality-ratio was 47%, varying between 0.38% in Ganzi (southwest China) to over 200% in Jiayuguan (arid northwest China). This median was seven percentage points higher than the scarcity threshold of 40%.⁹

- Comment 30: • Line 180: Is there any indication that water scarcity limits economic productivity?

– Response 30: Thank you for your question. From the latest literatures in 2021-2024, we have found the evidence⁹⁹, which is actually a hotspot to research. There are studies demonstrating that crop yield and industrial productivity would decrease due to water scarcity, which is accounted as economic loss of water scarcity at the prefecture level^{7,35,100}. Thus, consequences and influences of water scarcity, as well as drought, are significant and serious^{23,101}. That's why water conservation has long been recognized as an important institutional and social adaptation to climate change^{9,31}. We have also revised accordingly.

- Comment 31: • Line 191: Are there implications here for the quality of the data? Did you consider a sensitivity analysis or similar approach to determine reasonable ranges of water use, rather than providing only a single “best guess” value for each city? Data are discussed in the Methods, but some points could be added to the discussion.

– Response 31: Thanks for your questions and suggestions. Basically, our accounting methodology is a direct process-based approach, based on bottom-up censuses and surveys. It could also combine ‘top-down’ and ‘bottom-up’ metrics: input data, such as water withdrawal efficiency, are monitored data, yet all output data are through modelled estimation from *Case 1*) and *Case 2*). Thus, This study is a combination of monitored data and modelled estimates. This combination would avoid uncertainty induced by spatial allocation in the simple or traditional top-down methods¹⁰².

Yes, for sensitivity analyses, please refer to detailed discussion in the responses to Question No.28#.

- Comment 32: • Line 227: It would seem obvious to target the least efficient users. Can you explain, even briefly, why this is not done?

– Response 32: Thank you for your questions. We think China is not able to realize this because how to know and compare water use and efficiency are limited by the existing unavailability or dilemma on subsector data. As a newly-published *Perspective in Nat. Water*¹⁰³ appealed for making China's water-data accessible, usable and shareable, our data are transparent, comparable and available for free sharing and public use. Additionally, referred to the current literatures, to blindly cut down irrigation water-use would reduce crop supply of agriculture, and hinder China's food security¹⁰⁰. As a result, China has decreed its first national-level laws and regulations on water saving, which have taken effect since 1st May, 2024.

- Comment 33: • Figure 2: Values are given in RMB here, rather than dollars. It is better

to use one consistent currency. Further, are the units reversed? The figure legend says m³/yuan, but the values seem to be yuan/m³.

– Response 33: Thank you for your suggestions. We have revised these. This unit is of water-use, as illustrated in the second row of the legend.

- Comment 34: • Fig 3. The Supplementary Material provides the codes. Please add this detail to the caption.

– Response 34: Thank you for your suggestions. We have revised these.

- Comment 35: • Line 253: The term “scenario” is used here but not defined or explained. What are your scenarios? What specifically do they compare?

– Response 35: Thank you for your questions.

For individual sectors, we developed two scenarios to consider agricultural and industrial sub-sectors. Scenario 1 was in water-stressed prefectures for agricultural related sub-sectors (scenario 1.1: $5 \times 343 = 1,715$ sector-prefecture combinations), and for industrial related sub-sectors (scenario 1.2: $39 \times 272 = 10,608$ sector-prefecture combinations) (Fig. 5). In scenario 2, we assumed China would make water efficiency improvements across all prefectures (scenarios 2.1 and 2.2 in Supplementary Fig. 4). We substituted below-average water efficiencies with averages, assuming that technical progress in water use efficiency would enable low-efficiency sub-sectors to reach average levels. Specifically, technology is a vital factor underpinning different water intensities within one sector. For example, in Suzhou, electricity & hot water supply withdrawals were as much as 5.3 km³ p.a. (64% of total water use) due to the single-pass cooling technology used in 99% of its thermal plants. Transition to recirculating-cooling water would result in significant water savings⁴⁸. On the other hand, food or general-machinery manufacturing technology in Dongguan and Hanzhong, stood out as high-efficiency examples, and should be seen as benchmarks to peers in their national-sectors.

Concretely, if the water use intensity of a sub-sector in a prefecture was lower than the national sector-average, we left this water intensity as it was. Similarly, if water use intensity was higher but occurred in a prefecture with no water stress, we did not substitute, either. We only substituted intensities for sub-sectors with above-average water-use intensities in water-stressed prefectures with national sector-averages.

This approach is consistent with the metrics and standards used for instructing water withdrawals throughout China⁷⁻⁹.

In fact, a number of prefectures even require sub-sectors to utilize leading-edge technologies and regulatory standards for water savings in production since 2019¹⁰, i.e., benchmarked against the most efficient technology. Bearing in mind that we found some extremely high-intensity sub-sectors during our point-source surveys, and that there was large heterogeneity in water withdrawal and efficiency across prefectures for one national-sector, we estimated that using the national sector-averages would provide a useful guide. Furthermore, our scenario designation has distinguished whether a prefecture is located in water-scarce or not, as stressed by the latest research in *One earth* in 2024, etc.^{7,35}.

In addition to the water efficiency substitution in 180 water-scarce prefectures, we assumed China would also make water efficiency improvements across all prefectures. In other words, our normal scheme is a scenario for light water-saving, and our intensified scheme is a scenario for deep water-saving, as used in the literature⁹. And the nationwide water-saving scenario is also towards self-discipline for water conservation⁹. Our findings are in the Supplementary Fig. 4.

In these scenarios, we estimated the average and advanced levels of two important indicators, respectively, i.e., industrial water withdrawal intensity (withdrawal per economic output, m³ per million \$), and agricultural irrigation intensity (withdrawal per irrigated area, m³ per m²) at the prefecture level. By comparing before- with after- improvement, these scenarios and schemes could be useful for individual governments in terms of quota-designing, assessment and review on water-saving at the prefecture-sector combined levels throughout China.

Besides, we may regard settings of other water-use and future scenarios are based on exclusive modules or parameters^{31,59,104}, which could not be applied into the datasets of this manuscript.

- Comment 36: • Line 295: What is the National Water Saving Action Regulation? This explanation is not clear.

– Response 36: Thank you for your question. The National Development and Reform Commission, and the Ministry of Water Resources jointly released the ‘National Water-Saving Action Plan (Regulation)’ in April 2019. Since introduction of this plan, the Ministry of Water Resources has been persistent to prioritize water-saving, and collaborated with as many as 20 departments of the state council of China to improve water-saving coordination. The National Development and Reform Commission, and the Ministry of Water Resources have also issued detailed regulations on responsibilities of individual departments. The Ministry of Water Resources has instructed as many as 31 provinces (including autonomous regions and central municipalities) to put forward their own internal regulations at the province level. These regulations would promote primary actions as follows, dual-control on total amount and efficiency of water-use, agricultural and industrial water-saving and efficiency improvement, etc.^{11,12}.

We have also revised accordingly.

- Comment 37: • Line 310: SI Table 1 could be improved. What is the actual use and efficiency measure? What are comparable global averages or coefficients for the most efficient technology?

– Response 37: Thanks for your sharp suggestions. About the actual use and efficiency measures, as well as comparable global averages and coefficients, we fully agree with you, because we think such analyses would genuinely improve this manuscript to be more comprehensive for decision-making.

i.) about water-saving measures, we compiled and supplemented some information. We wish it would be useful. We summarized seven kinds of mainstream and emerging techniques, i.e., six for irrigation (applicable to cultivation of wheat and maize etc.) and one for power-generation, as listed in R. Table 8. In this process, on-site visits were used to gather data.

R. Table 8 A scheme of seven mainstream and emerging water-saving techniques.

Sub-sector	Type	Measure or technique	Definition	Saving potential (%)	Current status or area	Feasibility		Prospect (↑↓)
						Cost, expenses for applications (\$)	Optimal water use amount (m ³)	
Agricultural irrigation	Micro-irrigation	Drip irrigation ^{15,40-42} ; Subsurface drip (SSD); surface drip (SD)	40% in soil surface wetted ^{15,16}	50-80 [†]	Small area and expansion	Fixed investment: 2,200 per ha, plus 880 per ha per year for mulch etc. consumable*	1,800 per ha (winter wheat) ⁴³ , 5,907 (corn)	Continuous expansion, to be leading, with fertilizer & plastic mulch techniques ^{15,16,40}
		Sprinkler irrigation	60% in soil surface wetted ^{15,16}	30-60	485 k ha for wheat [*]	Cost higher than benefit; 75% irrigation time shortened.	N.A.	To decline in cultivated area
		Bubble irrigation	N.A.	30	N.A.	N.A.	N.A.	N.A.
	Irrigation through pipelines	Low pressure pipelines	N.A.	15-30	11,517 k ha	N.A.	N.A.	N.A.
	Canal seepage control	Canal leakage control	N.A.	15-30	N.A.	N.A.	N.A.	N.A.
	Furrow & canal	Canal & furrow	80% ^{15,16} , usually based on a constant interval ⁴⁴ , without moisture monitor	15	Dominating in China ^{15,16}	N.A.	6,822 per ha (corn)	To sharply decrease in cultivated area
Industrial power generation	Water recirculation cooling	Wet towers	Transition from single-pass to recirculating-cooling	97%, from 168 liters to 5 of water abstraction per kwh ⁴⁵	Less than 10% thermal plants [#]	Total generation costs at 0.05 per kwh ^{46,47}	159 million for electricity & hot water supply	Substantial room to reduce ⁴⁸

Note: 1) [†] there is no substantial gap in water-saving potential between SSD and SD. Data are from Tianjin city in 2023⁴². 2) * for Zhangbei county in Hebei province, north China. 3) ^{*} data is in 2014. 4) [#] for Suzhou city, in Jiangsu province, east China. 5) N.A. denotes none-available data at the current stage. 6) Full names of sector are indicated by ‘&’ for short, throughout the paper.

In 2014, micro-irrigation area of cultivated wheat of China is 952 k ha. In 2021, proportion of China's micro-irrigation area in total agricultural irrigation area is 16.89%, according to the International Commission on Irrigation and Drainage (ICID) database⁴⁹. Proportion of micro-irrigation area (11,816 k ha) in water-saving irrigation area (37,796 k ha) is 31%. Towards future, we predict that on one side, large-scale applications of these water-saving techniques are booming globally, especially in developing countries^{15,16}; On the other side, such applications should continue to rely on fiscal subsidies and promotions from government, because added inputs usually decrease profits of farmers⁵³. Currently, farmers alone are unwilling to adopt such water-saving techniques.

ii.) given that improving water-use efficiency is a slow and difficult process⁵⁶, at this stage, we find difficulty in obtaining or mapping such fined or detailed technical data as for each prefecture or sector³¹, i.e., specific techniques, accurate water-use amount for industrial output (\$) or agricultural crop (or irrigated area, in m²), water-saving coefficient and cost⁷. Concretely, 1) we could find techniques at the product and equipment levels, as Xu et al. (2024)⁵⁷ did, to cut down package-related water use. Other studies are through material flow and metabolism analyses⁹, agent-based models⁷ and life cycle analyses⁵⁷. 2) We could also find techniques typically within a certain sector⁷. In this regard, most research focus on cooling systems within the power-generation sector, or iron & steel sector⁵². Yet we find challenge in matching technique information.

This challenge stems from existing water policies³¹, in particular control on water-use price. For example, in coal-fired and power-generation sector of China, there is no substantial difference on generation costs from the one-through cooling techniques to circulation cooling techniques. Moreover, water-related cost merely occupies a small proportion in the total generation costs at 0.05 US\$ per kwh^{46,47}. The water-related cost ranks after fuel cost (1st), investment depreciation cost (2nd), and operating and maintenance cost (3rd), as a previous study find that at current water prices, commercial companies are unlikely to adopt water-conservation measures⁵³.

We would like to extend this part continuously in the future, as put in the reference³¹.

iii.) at last, in our results, we do find there are common characteristics, features and similarities in the targeted prefectures for water-saving (as listed in the Supplementary Table 3). To some extent, such similarity could support rationality and usefulness. Concretely, 1) they are faced with common challenges, such as water scarcity, pollution, and vulnerability to extreme weather events. For example, over-extraction of groundwater is a critical issue in these prefectures, leading to significant drops in groundwater levels and deterioration of water quality. 2) for agricultural-related prefectures, agricultural practices in these prefectures often involve inefficient irrigation methods, leading to high water wastage. Traditional flood irrigation is still prevalent, which is not sustainable in the long term. There is a lack of widespread adoption of water-saving technologies like drip irrigation and rainwater harvesting in many of these regions. 3) for industrial-related prefectures, i.e., Guangzhou, Shantou, Zhongshan, Huai'an, Suzhou, Taizhou, Hefei, and Nanjing, in terms of climate type, these prefectures are mostly located in the east and south of China, and fall into the subtropical monsoon climate zone. Their climate commonly exhibits distinct seasons, with hot and rainy summers vs. Cold and dry winters. Precipitations of these prefectures are commonly dominated by monsoonal circulation. Distribution and amount of precipitation are commonly subject to strongness and direction of monsoonal circulation change. 4) to address the common challenges is critical for future sustainability and health of the cities. Efforts to manage resources more effectively and improve water quality, are essential to mitigate the adverse impacts.

iv.) about the comparable global averages or coefficients, please refer to discussions in responses to Question No.26#.

- Comment 38: • Fig. 4: What does it mean if the grey shaded values (with the axis title on the right-hand side) are below zero? These are compared to the National Average across all sectors? Please explain. Also, the axis title “change of sector numbers (%)” is unclear. What does it mean?

– Response 38: Thank you for your questions. We have deleted these. Inner individual sector, it is used to represent variation ranges of intensities, considering that both numbers and fluctuations of individual sub-sectors are different from one sector to another. Each national-sector is broken down to exhibit its own average value.

The intended meaning is ‘change number of prefectures (%)’, as the same treatment in the latest research⁷. Typically, there will be more than a single prefecture-sector combination substituted in most national-sectors. We estimate these proportions, in percentage (%).

- Comment 39: • Fig. 5: Are all the global comparisons fair? Some of the countries listed have small populations and relatively large water supplies. The United States is missing. Slovak and Czech should read Slovakia and Czechia. It is also not clear where the Developed Countries (2030) values come from, what they mean, or how they were calculated. Some Chinese cities have two points and others have only one. Why is this?

– Response 39: Thank you for your sharp questions and detailed comments. We fully agree with you, and we have revised accordingly.

For a background information, the ‘three-redline’ water stringent-regulations have established to approach globally optimal levels of water-use intensities by the year of 2030.

About OECD and the US magnitudes, please refer to discussions in responses to Question No.26#.

We realized the accounting and then comparison from scratch. A nonnegligible fact on efficiency of current water use is that data are not readily available, as She et al. (2024) demonstrated⁷. For all the data presented in this study, we need to develop a general framework, to realize estimation on detailed and subsector water use. Unfortunately, for the time being, few published data on water-use exist, although China’s water issues are of international interest. As of 2024, as a foundation for water accounting, full monitoring or metering on agricultural water-use remains inadequate and needs to be supplemented, according to the National Development and Reform Commission of China, etc.^{22,34}. Thus such accounting is an emerging trend to lead. After all, we need to firstly obtain these figures to further reflect or reconcile on comparison and then its fairness. Besides, there is evidence predicting that global water-use efficiency tends not to improve quite substantially before 2050^{59,105}, so it is necessary to compare and change.

We delete these two points of ‘developed countries mid- and top-level intensities’, as we made a mistake here: they were actually from our coauthored but not yet peer-reviewed manuscript, which would bring uncertainty in this regard. We find removal of these would also leave this figure clearer.

We may wish to clarify the ‘one or two points’: in this figure, actually every prefecture has two points, which denote before- and after- the improvement, e.g., Shanghai vs. *Shanghai*’, Xi’an vs. *Xi’an*’. Some quite-advanced prefectures in terms of water-saving have little potential for improvement, and thus present overlapped positions before- and after- the improvement, i.e., these prefectures change quite slightly. Prefectures with distinguished two-points are those to be improved in future. We have also revised accordingly.

- Comment 40: • Line 389: There are not unlimited numbers of options in the US.

– Response 40: Thank you for pointing out this problem. We have deleted this. Sorry for not making it clearer.

- Comment 41: • Fig. 6 (and elsewhere): In many countries, municipal water systems also provide supply for some industries. Other industries are self-supplied. How was this point handled in the study? Or is the situation different in China?

– Response 41: Thank you for your questions and comments. No, the situation is not different in China. Municipal water system is basically from tap water production, which is eventually from surface water and groundwater, so is the ‘self-supply’. These two sources, i.e., surface water and groundwater, are directly reported in the statistics of water resources bulletins at the prefecture and province levels. In our dataset, we accounted all anthropogenic water use sourced from both surface water and groundwater, and did not split specialized tap water or self-supply proportions.

- Comment 42: • Line 449: There is no explanation of (A) here. Just (B) and (C).

– Response 42: Thank you for pointing out this issue. We have explained this.

- Comment 43: • Line 455: Can you provide the relative shares of cities in the case I category versus the case II category? Provinces in case II are listed later (line 484), but more detail here would help.

– Response 43: Thank you for your questions. Approximately two fifths of 343 prefectures do not collect or develop water data statistics, i.e., categorized into the *Case 2*. For data of the other three fifths of prefectures, there are only total numbers of six types provided, i. e., categorized into the *Case 1*. We have also revised accordingly.

- Comment 44: • Line 463: if the industrial type was not listed (case II), water use was allocated to industries by their value-added and water use intensity? How much did assumptions like this affect the totals calculated? Did you conduct a sensitivity analysis to produce even very general figures?

– Response 44: Thank you for your questions. Firstly, we hope to describe more details to clarify our methodology. Secondly, we acknowledge that this does result in uncertainty, please see detailed discussion on sensitivity analyses in the responses to Question No.28#. We have also revised these narrations accordingly.

i.) With regard to our methodology, we supplement in our main text that ‘Core and primary data of the Dataset on Water Use of China at the Sub-sector level (DWUCs) are from national pollution point-source census of the Ministry of Ecology and Environment. In the census and survey, we investigated 161,598 companies (approximately 42% of all above designated-size companies of China; above designated-size company referred to those with annual business revenue over 2.93 million US\$³⁶; exchange rate at US\$1 = ¥ 6.8174). Apart from carbon emissions, water withdrawal information collection was conducted, and industrial economic-output data were coupled with water-withdrawal data of companies. Then these data were subsequently aggregated according to sub-sectors to calculate the intensities, i.e., water withdrawal intensities for individual sub-sectors in each prefecture across 13,377 industrial sub-sectors for all 343 prefecture-level cities.

Our methodology applies a water balance principle between prefectures and provinces, i.e., water balance equations between provincial water use and its administered prefectures' water-use amounts³⁷. Adopted from the IPCC principles and elements, construction of our datasets was based on selection of 16 driving forces, according to each broad type. For example, disaggregated industrial output and water withdrawal per output of each sub-sector (*Intensity*). We connected a size indicator with corresponding water-withdrawal efficiency. Mechanisms of accountings for the other sectors are similar.

First of all, we need to do data-mining aiming at the 16 indicators, mainly from provincial and prefecture-level water resources bulletins issued by the *Ministry of Water Resources* and local *Hydrology and Water Resources Investigation Bureaus*, national pollution source census and regular reporting systems of the Ministry of Ecology and Environment, and provincial and prefecture-level statistical yearbooks (Figure 7). Then, we move into detailed estimations. We used a complete set of equations to describe all variables. Specifically, ① industrial water use (*WaterIndus*) accounting is as follows: we followed three procedures (A-C), and realized the prefecture level (B) partition, and then the sub-sector level (C).

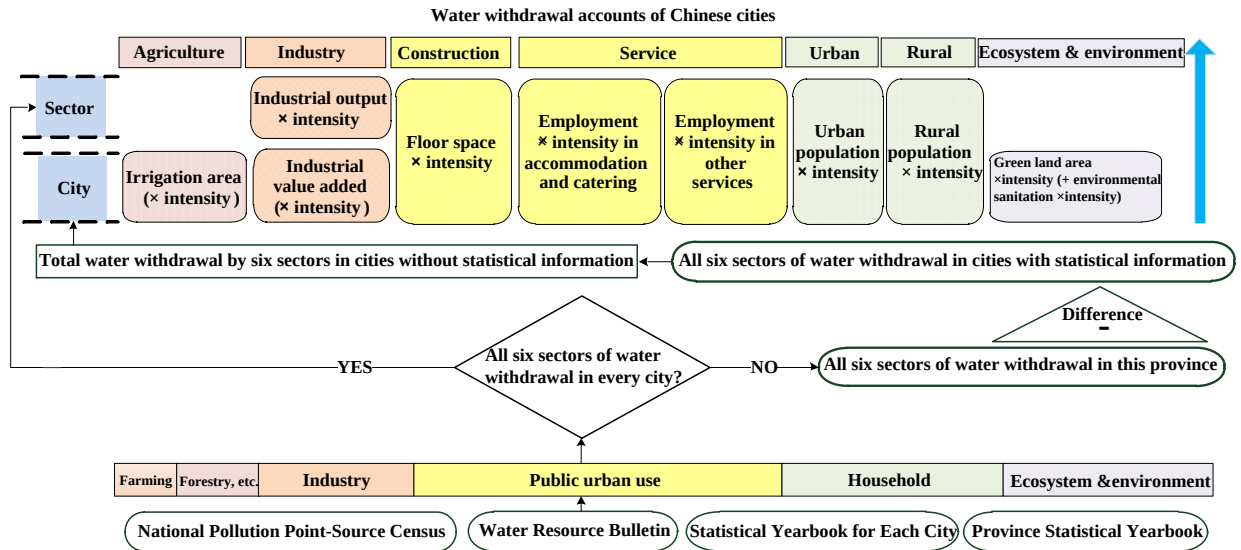


Fig. 7. A framework for subsector water withdrawal accounting at the prefecture level. The circled sources at the bottom indicate the primary data inputs used for estimation. This is in furtherance to our previous paper³⁸.

For (A), we compiled industrial water withdrawal for prefectures in a province from provincial water resources bulletins. There were two cases to consider based on data availability (please also see Figure 7 for intuitive illustrations):

Case 1) If water resources bulletin for a province provided industrial water withdrawal for every administrative prefecture, these data were compiled for later use in subsector partition. We allocated water withdrawal into each disaggregated sub-sector (in Supplementary Table 1) for each prefecture.

Case 2) If the water resources bulletin did not provide water withdrawal for industrial type for all administrative prefectures, we collected industrial water-withdrawal for each prefecture in their corresponding water resources bulletins. For those prefectures that did not have these data in their

respective bulletins, we calculated the difference between provincial water withdrawal and the sum of water withdrawal for all prefectures that did have statistics in their prefecture-level water resources bulletins, based on a water mass balance. In this way, we obtained a sum for all prefectures for which water withdrawal of industrial type was not included in their water resources bulletins.

For **(B)**, we allocated the sum of industrial type for those prefectures without statistics, based on two multipliers as driving forces of water withdrawal. We used total industrial value-added (*Valueadded*, size indicator) multiplying water withdrawal per value-added (*Intensity_i*) in the partition. According to data availability, for prefectures having data for both water withdrawal per value-added and total industrial value-added, we immediately obtained:

$$W_i = Valueadded_i \times Intensity_i / \sum_{i=1}^n (Intensity_i \times Valueadded_i) \quad (1)$$

$$WaterIndus_i = W_i \times SUM_{n_cities} \quad (2)$$

where i is a prefecture without statistics in the province and n represents the total number of prefectures without statistics in the same provinces. Industrial water withdrawal per value-added was sourced from water resources bulletins at the province and prefecture levels³⁹. Total industrial value-added was from province or prefecture statistical yearbooks. This case was considered to be a further step, going beyond previous studies, such as Guan et al. (2014)⁶, which assumed industrial water withdrawal per value-added was identical amongst regions. In the case of missing water intensity, we instead used total industrial value-added to calculate proportions to disaggregate water withdrawal.

For **(C)**, we used disaggregated industrial output and water withdrawal per output of each sub-sector (*Intensity_{i,k}*) to partition total industrial water withdrawal of each prefecture (*WaterIndus*). That is,

$$W_{i,k} = Intensity_{i,k} \times Output_{i,k} / \sum_{k=7}^{45} (Intensity_{i,k} \times Output_{i,k}) \quad (3)$$

$$WU_{i,k} = W_{i,k} \times WaterIndus_i, k \in [7, 45] \quad (4)$$

where k represents a sub-sector of prefecture i , and $WU_{i,k}$ is the subsector industrial water withdrawal of prefecture i . $W_{i,k}$ is the proportion of subsector and industrial water withdrawal in total industry water withdrawal. *Intensity_{i,k}* is the disaggregated water withdrawal intensity.

Output_{i,k} is subsector and industrial output of each sub-sector. *WaterIndus_i* is total industrial water withdrawal of prefecture i . Subsector industrial outputs were sourced from the statistical yearbook for each prefecture. These data were then proofed and corrected by the authors, according to the China City Statistical Yearbook. We regarded the China City Statistical Yearbook as consistent and true magnitudes. Industrial total water withdrawal and water-withdrawal per value-added were collated from water resources bulletins at province and prefecture levels.

In the prefecture module, methods of accountings for the other sectors' water use are similar as Industry. Concretely, ② estimation on agriculture water-use amount equates,

$$WU_{i,k} = Irriareas_{i,k} \times Intensity_{i,k}, k \in [1, 5] \quad (5)$$

We used the irrigation water withdrawal per *mu* of farmland, and the irrigation area to determine agricultural water use. $WU_{i,k}$ is irrigation water withdrawal of prefecture *i* for agriculture, $Irriareas_{i,k}$ is irrigation area of prefecture *i* for agriculture (represented by farming), and $Intensity_{i,k}$ is irrigation water withdrawal per *mu* of prefecture *i* (*mu* is Chinese acre, 1 *mu*≈667 m²). 1-5 denote the first five of 63 economic activities. Irrigation area was from provincial statistical yearbooks. Irrigation water withdrawal per *mu* for farmland was sourced from water resources bulletins at the province and prefecture levels³⁹. As there is little uncertainty, this case is considered an advancement of previous studies, such as Vardon et al. (2007)⁴, which used only the irrigation area by assuming that the irrigation water withdrawal efficiency was equal among regions.

③ we utilized the floor space of housing (*Flospac*), and the water withdrawal per unit (*Intensity*) to estimate water withdrawal for construction. Estimation on construction water-use amount equates,

$$WU'_{i,46} = Flospac_{i,46} \times Intensity_{i,46} \quad (6)$$

where $WU'_{i,46}$ is original water withdrawal of prefecture *i* for construction, $Flospac_{i,46}$ is floor space area of housing of prefecture *i* for construction (represented by completed floor space), and $Intensity_{i,46}$ is water withdrawal per floor-space area of housing of prefecture *i*. Water withdrawal per floor space of housing completed was from the Bulletin of 1st Water Resources Census (i. e., 2nd Water Resources Census of Shanghai by the Shanghai Bureau of Statistics and Water Authority). Floor space of housing was from provincial statistical yearbooks.

④ For water withdrawal for accommodation & catering sector, which is usually the largest water user in the service, we assumed a positive correlation between water use and the number of employees, and then used employment and water withdrawal per employee (*Intensity*). Estimation on service water-use amount equates,

$$WU'_{i,49} = Employment_{i,49} \times Intensity_{i,49} \quad (7)$$

$$WU'_{i,k} = Employment_{i,k} \times Intensity_{i,k}, k \in [47, 48] \cup [50, 60] \quad (8)$$

$WU'_{i,49}$ is original water withdrawal of prefecture *i* for accommodation & catering sub-sector, $Employment_{i,49}$ is number of employees of prefecture *i* for accommodation & catering sub-sector (as key water user), and $Intensity_{i,49}$ is water withdrawal per employee of prefecture *i*. Similarly, $WU'_{i,k}$ is original water withdrawal of prefecture *i* for the other services other than accommodation & catering sub-sector (as ordinary water users), $Employment_{i,k}$ is number of employees of prefecture *i* for the other services other than accommodation & catering sub-sector, and $Intensity_{i,k}$ is water withdrawal per employee of prefecture *i*. Water withdrawal per capita in representative accommodation & catering, water withdrawal per capita in other services, were from the Bulletin of 1st Water Resources Census (i. e., 2nd Water Resources Census of Shanghai by the Shanghai Bureau of Statistics and Water Authority). The number of employees in accommodation & catering and other services were from China City Statistical Yearbook.

⑤ we used the rural population (*Popul*, permanent residents), and household water withdrawal per resident in rural areas (*Intensity*) to estimate rural household water withdrawal. The estimation for urban household water withdrawal was quite similar. Estimation on household water-use amount equates,

$$WU'_{i,k} = Popul_{i,k} \times Intensity_{i,k} \quad (9)$$

$$W_{i,k} = WU'_{i,k} / \sum_{k=61}^{62} WU_{i,k}, k \in [61, 62] \quad (10)$$

where $WU'_{i,k}$ is original water withdrawal of prefecture i for household, $Popul_{i,k}$ is rural (or urban) population of prefecture i (represented by number of permanent residents), and $Intensity_{i,k}$ is household water withdrawal per resident in rural (or urban) areas of prefecture i .

$W_{i,k}$ is the proportion of rural (or urban) household water withdrawal in total household water withdrawal. Rural and urban population (permanent resident) were from provincial statistical yearbooks. Household water withdrawal per capita in both rural and urban areas were from province or city statistical yearbooks.

After completing prefecture module estimations, subsector module equations contain,

⑥ estimation on construction and service water-use amounts equate,

$$WU_{i,k} = WU'_{i,k} / \sum_{k=46}^{60} WU'_{i,k} \times (WU_{i,UrbanPublic}), k \in [46, 60] \quad (11)$$

We used the proportions of water withdrawals (original magnitude indicated by $WU'_{i,k}$) in construction, accommodation & catering and other services, to separate urban and public water withdrawal. This procedure is more plausible than that used in Guan et al. (2014)⁶, which assumed that the water efficiencies of construction and all services were the same. $WU_{i,k}$ is disaggregated and subsector water withdrawal for construction and services of prefecture i . $WU'_{i,k}$ is the original and subsector water withdrawal for construction and services of prefecture i . $WU_{i,UrbanPublic}$ is total urban and public water withdrawal of prefecture i . Please note that the public water withdrawal in urban areas is defined as the sum of the water withdrawal for construction and all the services. This definition of water withdrawal is a statistical feature that is different from other energy, resource or economic statistics.

⑦ estimation on household water-use amount equates,

$$WU_{i,k} = W_{i,k} \times WU_{i,Household}, k \in [61, 62] \quad (12)$$

$W_{i,k}$ is the proportion of rural (or urban) household water-withdrawal in total household water-withdrawal. It is used to partition total household water-withdrawal into rural and urban household sub-sectors, on an occasion that we could only get a total number of household water-withdrawal.

$WU_{i,k}$ is disaggregated and subsector water-withdrawal for rural or urban household of prefecture

i . $WU_{i,Household}$ is total household water-withdrawal of prefecture i .

⑧ we used the area of green land, irrigation volume per green-land area (*Intensity* equals 0.0782 cubic meters), environmental sanitation areas (*Sanitarea*), and the water withdrawal per unit (*Intensity'* equals 0.0265 cubic meters) to estimate ecosystem and environment preservation water-withdrawal. Estimation on water-use amount of ecosystem and environment equates,

$$WU_{i,63} = Greenland_{i,63} \times Intensity_{i,63} + Sanitarea_{i,63} \times Intensity'_{i,63} \quad (13)$$

where $WU_{i,63}$ is water withdrawal of prefecture i for ecosystem and environment, $Greenland_{i,63}$ is area of green land of prefecture i (represented by urban green land areas at this stage), and $Intensity_{i,63}$ is irrigation volume per green-land area in urban areas of prefecture i . $Sanitarea_{i,63}$ is environmental sanitation areas of prefecture i , and $Intensity'_{i,63}$ is water withdrawal per unit of prefecture i . Irrigation water withdrawal per green-land, and water withdrawal per environment and sanitation area, were from the Bulletin of 1st Water Resources Census (i. e., 2nd Water Resources Census of Shanghai by the Shanghai Bureau of Statistics and Water Authority). Environmental sanitation area was taken from statistical yearbooks for each city. Green land area was from China City Statistical Yearbook. Detailed meanings of abbreviations are also shown in Figure 8 and Table 1.

Besides, in the subsector module, for farming subdivisions, we calculated proportions of irrigation for cultivation of five main crops in 343 prefectures from Zhou et al. (2020)³⁷. Water withdrawal per irrigated area by crop was calculated based on the irrigated area data from Zhou et al. (2020).

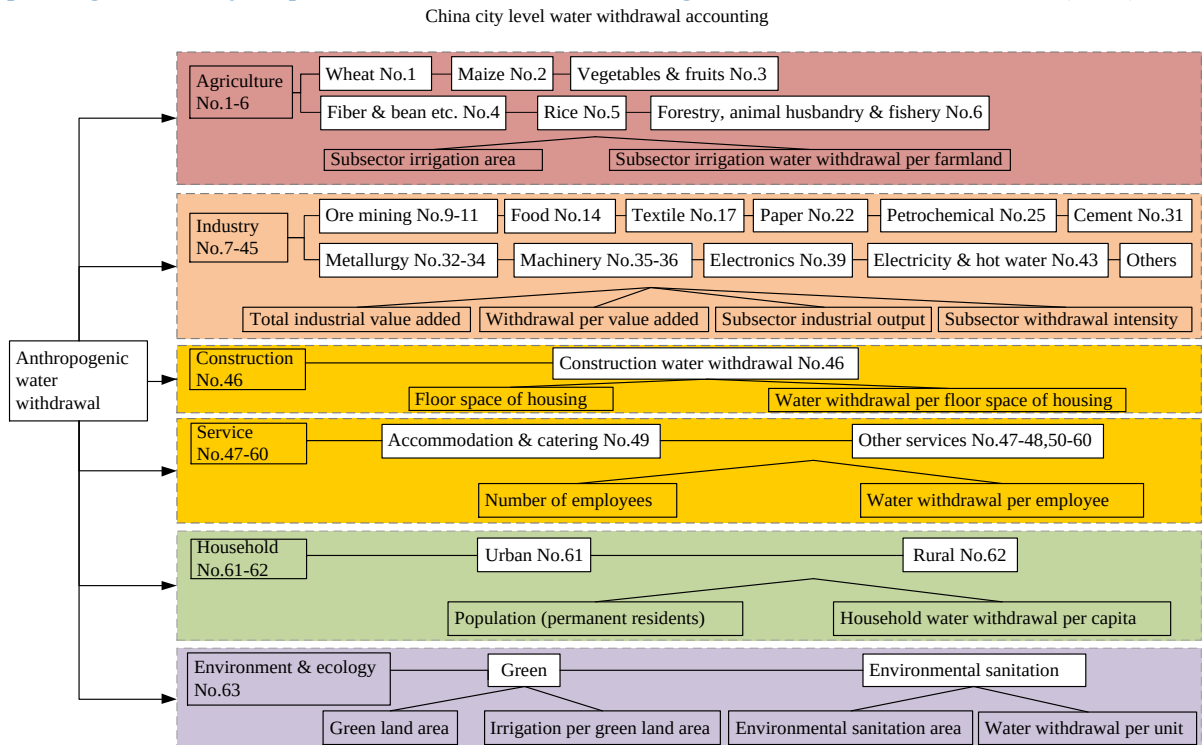


Fig.8. Indicators for prefecture-level and subsector water-withdrawal accounting and classifications. It is based on selections of 16 driving forces for water withdrawal datasets.

Overall, approximately two fifths of 343 prefectures do not collect or develop water data statistics, i.e., categorized into the *Case 2*. For data of the other three fifths of prefectures, there are only total numbers of six types provided, i. e., categorized into the *Case 1*. Concretely, prefectures from Jiangsu, Zhejiang, Guangdong, Anhui, Hainan, Heilongjiang, Tibet, and Jilin were categorized as *Case 2*. The remaining prefectures were in *Case 1*. For methodological validation, please refer to detailed discussions in references ^{29,30,38}, and Turner et al. (2010) ²⁴.

Table 1 Driving-force indicators and their sources.

Table 1 Driving force indicators and their sources.				
Agriculture		Irrigation area	○	○ Province statistical yearbook
		Irrigation water withdrawal per mu of farmland	√	
Industry		Total industrial value-added	○/Δ	Δ City statistical yearbook
		Water withdrawal per industrial value-added	√	
		Subsector industrial output	Δ	○/Δ Province or city statistical yearbook or internet search
		Disaggregated water withdrawal intensity of each sector	※	
Construction		Floor space of housing	○	√ Water Resource Bulletins
		Water withdrawal per floor space of housing	X	
Services	Accommodation & catering	Number of employees in accommodation & catering	U	※ National Pollution Source Census and Regular Reporting Systems of the Ministry of Ecology and Environment
		Water withdrawal per employee in accommodation & catering	X	
	Other services	Number of employees	U	
		Water withdrawal per employee in other services	X	
Household	Rural	Rural population (permanent residents)	○	X the Bulletin of 1 st Water Resources Census (i. e., 2 nd Water Resources Census of Shanghai by the Shanghai Bureau of Statistics and Water Authority)
		Household water withdrawal per capita in rural areas	○/Δ	
	Urban	Urban population (permanent residents)	○	
		Household water withdrawal per capita in urban areas	○/Δ	
Ecosystem & environment		Area of Green land	U	U China City Statistical Yearbook
		Irrigation volume per area of green land in urban areas	X	
		Environmental sanitation area	Δ	
		Water withdrawal per unit	X	

Note: this is in furtherance to a previous publication³⁸.

Overall, our methods have been the most up-to-date accounting approaches so far. In particular, She et al. (2024) has regarded our methodology as useful: the study pointed out the unavailability of detailed water-use data at the subsector level, then stressed that, our methodology should be used to construct water-use accounts to severely robust its conclusions. This study considered its numerical results might be uncertain, due to assumptions made in the absence of prefecture-level water-use data⁷. Besides, our methodology is preferable to simplistic ‘monetary amount and price’ methods^{7,35}.

ii.) Secondly, please see detailed discussion on sensitivity analyses in the responses to Question No.28#. We have also revised these narrations accordingly.

- Comment 45: • Fig. 7: Are the frequency values on the right-hand axis correct? Should they be up to 25% rather than 0.25%? The “trendline” is really a smoothed version of the frequency line, isn’t it? Perhaps rename it. Note that the body of the paper around this page seems to become Results rather than Methods. Was that intentional? If it is still methods, rephrasing would help.

– Response 45: Thank you for your detailed questions. We acknowledge this is easy to mislead, and have revised it.

Yes, it is a smoothed version of the frequency line. And we have revised this figure and the paragraphs accordingly. Thank you for pointing out these problems.

- Comment 46: • Figure I in the Supplementary Materials is not clear to me.

– Response 46: Thank you for your comments. We have revised this figure and supplemented some clarifications accordingly.

Appendix

A list of 20 prefectures used to calculate the water withdraw per service-employee from the prefectures with statistical information at the national level:

Xiamen;

Shenzhen;

Zhengzhou;

Qingdao, Laiwu;

Lianyungang, Huai'an;

Wuhan, Huangshi, Shiyan, Yichang, Xiangyang, Ezhou, Jingmen, Xiaogan, Jingzhou, Huanggang, Xianning, Suizhou, and Qianjiang.

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- Comment 1: First of all, please allow me to apologise for the delay in sending a decision on your manuscript titled "High-resolution water datasets show targeted water-saving opportunity in megacities from China". It 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, under the condition that you incorporate supporting evidence from the rebuttal letter into the main manuscript text as suggested by our reviewers.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. For publication in Communications Earth & Environment, we request that you:
*** Include relevant tables (sensitivity analysis) and figures from the response file in either the main text or supplementary materials to enhance clarity and provide complete supporting evidence.

- Response 1: Thanks. We have incorporated the supporting evidence from the rebuttal letter into the main manuscript text and supplementary materials, as suggested by reviewers. We have added these results including sensitivity analyses into both the main manuscript (briefly) and Supplementary Information, of which the tables on sensitivity analyses are included in the Supplementary Information.

- Comment 2: *** Verify that all sections have been thoroughly revised based on reviewer feedback, particularly in areas where outdated terminology or unresolved comments remain. In particular, incorporate your response to reviewers' comments 10, 12, 26, 27 and Table 3 into main text.

- Response 2: Thanks. We have added our responses to reviewers' comments 10# (into the Discussion section of the main text and Supplementary Information), 12#(Supplementary Information), 26# (Results section), 27#(Introduction section) and R. Table 3 (Discussion section).

- Comment 3: ***Provide deeper discussion on data quality and improvements (comment 28)

- Response 3: Please find in response No.9#.

- Comment 4: clarify industrial water use (comment 41) as requested by reviewer 2.

- Response 4: Please find in response No.10#.

- Comment 5: 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. EDITORIAL REQUESTS: Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table". *****Please take care to match our formatting and policy requirements. We will check revised manuscript and return manuscripts that do not comply. Such requests will lead to delays. ***** Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files as a Related Manuscript file.

- Response 5: Yes, we have confirmed and revised. Thanks again for your detailed instructions.

REVIEWERS' COMMENTS:

Reviewer #3 (this is the original Reviewer #1)

(Remarks to the Author):

- Comment 6: Review for the paper entitled: “High-resolution water datasets show targeted water-saving opportunity in megacities from China”. Thanks for responding to the comments. The comments were answered perfectly in the response to the comments file. However, for some comments, the explanations should be added to the manuscript as well. The related tables should either be added to the main manuscript or the supplementary materials. Comment 1 (9 in the response file): Four steps (limitations) were mentioned enough and concisely. Comment 2 (10 in r s file): The answer to the comment is very perfect; however, please bring these explanations in the corresponding section of the manuscript as well (I believe the introduction). Some tables and figures are available in the response to the comments but not in the main manuscript or the supplementary materials. For example, “R. Table 3. Comment 3 (11 in r s file): The manuscript now is more paper-wised. Comment 4 (12 in r s file): You responded very in detail which is good but please bring these explanations in the manuscript, concisely. Comment (13 in r s file): The figure was modified and improved. Minor comments 6 to 12 (14 to 20 in r s file): Responded.

- Response 6: Thanks. We have incorporated these from the rebuttal letter into the main manuscript text and supplementary materials as you kindly suggested, including the R. Table 3 (into the Discussion section of the main text). Thank you for helping us refine the rebuttal letter based on our manuscript, we have accepted and followed these. We appreciate your guidance and effort.

Reviewer #2 (Remarks to the Author):

- Comment 7: The authors have significantly improved the manuscript from the first submission. In particular, the methods are expanded and much clearer. I also appreciate the very detailed comments on the revisions, which run to 53 pages! The article contributes greatly to the available information on water use in China and should be accepted for publication subject to very minor revisions. A few general remarks follow, before a short list of specific revisions. My original comments on “cities”, methods and Chinese data, sectors vs. sub-sectors, efficiency figures, criticality ratio, water scarcity effects on economic productivity, application of consistent units, and scenario definitions were addressed well. However, many of the responses were confined to the rebuttal itself, while my intention was to highlight points to be revised in the manuscript itself. Specifically, the details in comment 26 would be of interest to the general reader and not just me; residential water use should not be left to a subsequent publication – or if it is, the reasons should be explained to the reader (comment 27);

- Response 7: Thanks for your detailed instructions. We have supplemented into the main text and made the corresponding modifications.

In our responses to the original comment No. 27#, due to both word-count and display-item limits, at this stage this study may wish to focus on the productive and main water withdrawal, considering

the fact that 1) average share of agricultural irrigation occupies approximately 60%; 2) industrial water withdrawal is ranked the first in 17% of prefectures, and the first-two places in 97% of prefectures among productive water withdrawal ^{1,2}. Sometimes, we do observe there are research separating productive water-withdrawal ³⁻⁵ and residential water-withdrawal ⁶⁻⁸, i.e., these residential water-withdrawal parts are somehow independent from productive water-withdrawal assessment.

Also, please refer to and combine response No.10# below to fully understand this aspect. Thanks again for your persistent inspires from different angels.

- Comment 8: sensitivity analyses are important and the results in the rebuttal should be added to the main manuscript (at least briefly),

- Response 8: thanks. We have added these results into both the main manuscript and Supplementary Information.

- Comment 9: but my point in Comment 28 was that reported water use by a timber and straw processing company in Liaoyang of 0.046 m³ (46 litres in a year?!) is not believable. This says something about data quality. The paper is very results-oriented, and some deeper remarks on data quality and its improvement would add a useful analytical dimension. There are some thoughtful comments on water policy in the rebuttal that would be useful to add to the manuscript.

- Response 9: Thank you for carefully pointing out this problem. We have removed these statements. We appreciate your wisdom.

Regarding discussion on data quality (the original Comment No. 28#) and improvements, we may wish to compare with Zhou et al. (2020)⁹, which is an important and previous publication in the field. Zhou et al. (2020) provided data before 2013. In details,

1) we compared water withdrawal gaps between our estimates and Zhou et al. (2020)⁹. We chose 13 Beijing-Tianjin-Hebei prefectures in 2012, considering these prefectures to be ones with the most severe water-scarcity issues. For validation, we additionally estimated 2012 data using an identical methodology¹. For review, these data were attached separately and extendedly as time-series datasets.

R. Table 1 A comparison of water withdrawal (100 million m³)

Prefecture	Farming			Industry			Urban household			Rural household			Total		
	Zhou et al. (2020)	This study	Gap (%)	Zhou et al. (2020)	This study	Gap (%)	Zhou et al. (2020)	This study	Gap (%)	Zhou et al. (2020)	This study	Gap (%)	Zhou et al. (2020)	This study	Gap (%)
Baoding	21.13	22.76	-7	1.58	1.18	<u>34</u>	0.83	1.57	<u>-47</u>	2.13	1.88	<u>13</u>	26.25	31.09	<u>-16</u>
Cangzhou	7.75	9.02	<u>-14</u>	0.52	1.08	<u>-51</u>	1.12	0.74	<u>50</u>	0.86	1.14	<u>-25</u>	11.12	13.91	<u>-20</u>
Chengde	6.17	5.71	8	1.42	1.02	<u>40</u>	1.06	0.80	<u>33</u>	0.96	0.88	9	9.89	9.16	8
Handan	11.48	14.02	<u>-18</u>	1.86	1.83	1	2.93	1.17	<u>150</u>	2.38	1.38	<u>72</u>	20.17	20.72	-3
Hengshui	12.27	12.80	-4	0.81	0.69	<u>17</u>	1.25	0.45	<u>177</u>	1.10	0.66	<u>67</u>	16.05	15.77	2
Langfang	6.11	5.72	7	0.84	0.79	6	2.36	0.86	<u>174</u>	0.59	0.88	<u>-33</u>	11.18	10.26	9
Qinhuangdao	5.49	5.27	4	0.98	0.94	4	1.52	0.71	<u>114</u>	1.03	0.70	<u>47</u>	9.54	8.88	7
Shijiazhuang	19.94	20.69	-4	2.81	2.04	<u>38</u>	2.76	2.38	<u>16</u>	2.39	1.85	<u>30</u>	29.34	31.89	-8
Tangshan	16.95	14.32	<u>18</u>	4.84	4.82	0	2.61	2.29	<u>14</u>	2.41	1.68	<u>44</u>	28.63	25.97	<u>10</u>
Xingtai	13.00	13.29	-2	1.71	1.24	<u>38</u>	1.28	0.69	<u>85</u>	1.24	1.12	<u>10</u>	17.75	18.12	-2
Zhangjiakou	7.97	7.40	8	1.21	0.82	<u>47</u>	1.39	0.51	<u>171</u>	0.78	0.85	-7	11.67	10.56	<u>11</u>
Tianjin	7.11	*	-	5.36	5.10	5	7.29	*	-	1.18	*	-	26.24	23.10	<u>14</u>
Beijing	7.16	*	-	4.90	4.90	0	10.14	*	-	0.58	*	-	28.48	35.90	<u>-21</u>
Total	128.27	130.99	-2	28.85	26.45	9	19.10	12.18	<u>57</u>	15.87	13.01	<u>22</u>	246.31	255.33	-4

Notes: i) gaps >10% are highlighted; ii) * means not disclosed in the Bulletin; iii) the GDP deflator was calculated as 1.098 between 2010 and 2012¹.

In R. Table 1, water withdrawals for farming were basically close in these two studies. Total water withdrawal of Zhou et al. (2020) was 2% lower than that of this study, on average. For industry, water withdrawal was 10% lower than that in this study, on average. For rural households (defined as water withdrawal for livestock and poultry-breeding, according to Zhou et al. (2020)), water withdrawal was 22% higher than this study, on average. For urban households (including service, according to Zhou et al. (2020)), water withdrawal was 57% higher than this study, on average. Overall total water withdrawal was 4% lower than this study, on average. The reasons could be twofold: 1) We have different calibres for agriculture/industrial water use. Data were from different sources i.e., prefecture Water Resources Bulletins (this study), and provincial and national Water Resources Bulletins simulation (Zhou et al. (2020)); and 2) there are merge and separation between prefectures in historical statistics.

2) One of the advantages of our dataset over Zhou et al. (2020)'s is in disaggregated and detailed information through partitioning. For example, for industrial sectors, we have at least 41 while Zhou et al. (2020) has 7 (our 'sector' is selected according to the widely used classification of the national accounting system i.e. classification for national economic activities, released by the National Administration for Quality Supervision, Inspection and Quarantine). We therefore dig further into sub-sector detail.

3) Last but not least, Zhou et al. (2020)'s dataset could not really be regarded as readily available for public use. Because the published paper removed prefecture-name etc. information and only left some codes to represent a prefecture. What's worse, Zhou et al. (2020)'s method is neither open released to allow transparent comparison. Reading through the publication, one could only generally guess that its dataset was estimated from simulation (including simulation on some sectoral and economic value-added), rather than fully measured-efficiency data. From this perspective, Zhou et al. (2020)'s dataset may not be regarded as a systematic product. Distinct from this publication, our paper is aimed at opening up and publicizing water use data. We wish to continuously generate these data and develop professional datasets.

Actually, for sectoral data, availability limitations result in little observed or comparable data. For total amounts, although they are reported directly in official and public statistic bulletins, different bulletins at the different administrative levels (prefecture and province), or from different governing ministries i.e., Ministry of Ecology and Environment (as in our study) and Ministry of Water Resources⁹ have inconsistencies and even contradictory problems. For example, the PNAS paper from Peking University⁹ apparently make it likely for a validation, yet even Zhou et al. (2020) has large uncertainties because it contradicts itself. Unfortunately, the Zhou et al. (2020) study should be one of the few suitable comparisons we could find. Although some reasons could be given and explained as provided in our study, other data-source information etc. are hard to review or trace back, due to partial release of information and conservative sensitivity of government about water issues. Some original survey data could be regarded as confidential in China. These are the challenges and difficulty of data comparability, quality and reflection.

4) In summary, to the best of our knowledge, this dataset is the most disaggregated and open to-date. We would write a formal query to other relevant authors about this difficulty, in order to connect,

discuss, communicate in person, and make efforts towards finding a way through cooperation to solve these problems. Thanks again for your detailed instructions. We have supplemented and made the corresponding modifications.

- Comment 10: Response 41 does not really answer my question. Specifically, was it possible to estimate industrial water use for industrial users of municipal sources? Or were these industrial users classified as municipal (and therefore residential) users? I leave it to the editor and associate editor to determine whether these points should be addressed in the manuscript.

- Response 10: Thank you for your further questions and comments. We apologize not making it clear in the first round, bringing you confusions: At the current stage, it is not possible to estimate industrial water use for industrial users of municipal sources; these industrial users were not classified as municipal (and therefore residential) users.

Municipal water system is basically from tap-water production, which is eventually from surface water and groundwater, i.e., precipitation including rain and snow etc.. The ‘self-supply’ usually pump and withdraw water from rivers, lakes, marshes, sea, as well as groundwater. These two sources, i.e., surface water and groundwater, are directly reported in the statistics of water resources bulletins at the prefecture and province levels. In our dataset, we accounted all anthropogenic water use sourced from both surface water and groundwater, and did not split specialized *industrial water use for industrial users of municipal sources*.

At last, actually we infer that ‘municipal’ water statistics should be commonly used in many countries except China, because to the best of our knowledge, it is not a routine indicator within China’s own statistical calibres.

- Comment 11: Specific comments: • The authors should explain the addition to the authorship list, Geng Niu. This is already a lengthy authorship list, and all authors should have contributed materially to the study

- Response 11: Thanks for your kind reminders. For last round’s revisions, Geng has contributed a lot: he sought out new data and helped Zongyong analyzed many detailed data-sources. We confirm that all authors have contributed materially to this study. Thanks again for your comprehensive attention.

- Comment 12: • Line 107 mentions “city-level” water use. Should this read “prefecture-level”? • Figure 3’s vertical axis uses “city”. Please ensure that “city” and “prefecture” are used consistently. • Line 515 mentions “city” again. It appears that this section was not revised with the prefecture term

- Response 12: Thanks. We have revised these.

- Comment 13: • Figure 4’s caption has an “&”. I do not know what this means

- Response 13: Thanks for your detailed comment to point out this problem. We have deleted this.

- Comment 14: • Lines 373 and 374: what is the difference between cloth manufacturing and clothing manufacturing in practical terms? Do they occur in different regions? Do they use significantly different volumes of water, or is their water intensity different? The reader will wonder why they are listed separately.

- Response 14: Thanks for pointing out this problem. We apologize not making it clear in the first round, bringing you confusions.

Cloth manufacturing is textile, including from cotton to intermediate products, such as fiber, yarn, cloth and other materials, which is the national economic-sector No.17# in the Supplementary Table 1. Clothing manufacturing is from fiber and yarn etc. to final clothing products, such as apparels, footwears, trims and hats, which is the national economic-sector No.18# in the Supplementary Table 1. They pertain to different products and industrial sector-committees. In terms of water-saving potential, clothing manufacturing is ranked 1st (the largest), and cloth manufacturing ranked 3rd among all the national industrial-sectors (please see more details in Figure 5). These two sectors are listed separately in the standard and widely-used classification of national accounting system, i.e., classification for national economic activities, released by the National Administration for Quality Supervision, Inspection and Quarantine ^{10,11}.

We have revised and incorporated these.

- Comment 15: • Please explain the “IPCC” acronym and cite a reference where it first appears

- Response 15: Thanks for your detailed comment. We have revised these.

Finally, thank you for your penetrating judgment again, which is a clear mirror for our study. We have also gone through and confirmed the comments in your earlier round of review, to double check and remove mistakes as far as possible. We found indeed they were useful and we revised accordingly. We think all of your detailed inputs are worthy of deeper discussions.

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