

Interactive comment on “Socio-hydrologic perspectives of the co-evolution of humans and water in the Tarim River Basin, Western China: the Taiji–Tire Model” by Y. Liu et al.

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Response to general comments:

0. This is an interesting paper that is suitable for publication in the special issue of HESS. The authors made genuine efforts to understand the socio-hydrology of the Tarim River basin in China. It is particularly intriguing how different combinations of natural forces and social processes affect the rise and fall of settlements in the TRB, and in turn the human-water interactions. The manuscript shows a rare bold attempt to unravel complex interactions between human and water using various sources of

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historical records. The manuscript can be improved by considering the following points

Answer: We thank the reviewer for the positive comment on the manuscript. We appreciate the reviewer's constructive advice and brilliant ideas about future research directions for socio-hydrology. We look forward to future exchange of ideas and cooperation, should an opportunity arise.

1. The manuscript can be better organized. I suggest that the authors shorten the description of historical background of the study area and focus more on the connection to the socio-hydrology of the basin. The conceptual Taiji-Tire framework can be placed earlier since most western readers are more familiar with deductive reasoning. Some repeated paragraphs can be better synchronized into one place.

Answer: Thanks very much for the comments. We provided the brief historical background of the SHS in TRB in order to give readers a general description to help them understand the more detailed discussions that follow. We have shortened the background by moving some parts to sections that focus on specific stages. For example, we moved the paragraph about Silk Road to Sect. 4: natural stage, as represented in manuscript p. 13 Line 375-385.

As for the Taiji-Tire framework, in the previous version we put this part later because we believed that in this way we can more clearly show how we can summarize the outcomes of the paper in the form of a model, but we do agree with the reviewer that this can cause confusion. We have now followed the advice of the reviewer and have moved the Taiji-Tire model earlier to Sect. 3, immediately after Sect. 2. We have also revised the description to reflect that this model is now used as the organizing framework for the rest of the paper.

2. The Taiji-Tire model can be improved. Since both internal and external factors can interact with each other and shape the socio-hydrology system, it might be better to use a dashed line for the inner circle and a solid line for the outer circle. The authors also consider placing some arrows to show the linkages between the inner and outer

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domains. This revised diagram also closely mimics the actual shape of a tire. It is unclear why the Taiji symbol is included in the center. The authors need to explain how the original Taiji symbol is linked back to their Taiji-Tire model. The Taiji symbol implies that the human system can drive the water system or vice versa. Is this what the authors attempt to explain?

Answer: We thank the reviewer for this comment. We use the solid line to separate the inner Taiji and the outer Tire to illustrate the interaction between the external factors and internal factors. The dashed line of the outer Tire indicates that the boundary of the tire is somewhat uncertain, and requires that we consider the interactions between scales. For this reason we argue that it might be better to keep the line as it was.

Following the advice of the reviewer we have now deleted the Taiji symbol in the center to avoid possible misunderstanding. Originally we thought the Taiji symbol may help readers who are not familiar with the Yin-Yang. We have also decided not to add more arrows, because we need more time to study about the interacting processes and this is left for future research.

That we use the Taiji concept to explain human-water relation is based on the understanding that the human system and water system are interacting at times and that the subsystems are driven by each other.

Please note that the previous Fig. 8 about the Taiji-Tire model is now Fig. 3, due to that we have moved the Taiji-Tire model earlier as Sect. 3.

3. The authors might consider including a table or a diagram illustrating internal and external drivers of change. It might be worthwhile to distinguish external forces (war between Tang and Arab States, global scale climate change, new technology) from internal forces (internal social organization, regional climate change). In other words, how did the global scale change affect the regional dynamics of socio-hydrology of the basin?

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Answer: We use the Taiji-Tire model to provide a general explanation of socio-hydrological processes and events. The external and internal forces are classified in terms of how the forces influence the scales and contents of the water consumption. For example, farmer's organization is the internal factor because it directly affects the farmer's irrigation behavior and the water allocation in villages, while the social regime is an external factor that indirectly affects the water consumption by influencing internal factors. What factors should be considered and how to quantify them are still not completely clear, and will be addressed in our future work. We have noticed the phenomenon that larger scale changes affect the regional dynamics of socio-hydrology.

For instance, the rise and fall of Dynasties of China have significant impact on the basin's SHS. We realized that the outer Tire should not be simply regarded as whole and external factors should be re-examined by different scales (this is also why we use dashed line to represent the outer boundary of Tire). There may exist multiple tires: the outer one (which represents social and natural conditions at a larger scale, e.g., China as a whole) can affect the inner one (which represent social and natural conditions at a smaller scale, like TRB), and finally the influences are passed over to the boundary between Tire and Taiji. We believe the Taiji-Tire diagram is sufficient for our current purposes, and choose not to include a table as requested by the reviewer.

4. The authors can discuss any legacy effects (time lag between changes in the social system and changes in hydrology) such as political upheaval or economic reforms on human-water interactions. How did the transition from traditional agrarian economy to communist economy to a mixed market driven economy affect the human interactions with water in the study area and the exchange with outside of the study area? How has the relative influence of internal and external social and biophysical factors changed over time? How did the rate of human-water interactions change as a result of changes in political economy in the nation?

Answer: The reviewer's ideas are interesting. We have noticed that there exists some kind of legacy effect in the human-water interactions at specific temporal scales. For

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example, during the period of social unrest (1920s-1940s, discussed in Sect. 5.2), the population and farmland area in Hotan did not vary simultaneously. The population had a delayed response to the farmland changes being more sensitive to the policies.

We have discussed the co-evolution of the SHS in TRB during past 2000-yr. and we demonstrated the process of how the water consumption expanded and humans and water interacted. More specific focus on the impact of single variable such as economy (agrarian to communist to mixed market driven economy) is needed and we will definitely put it on our research agenda. The other questions the reviewer raised are also constructive and we totally agree that all these questions need to be answered, but perhaps in the future.

5. The authors place the importance of their research better in the context of other related research in socio-hydrology. If the intent of this article is to provide insights for comparative socio-hydrologic studies around the world as stated in the introduction, the authors can compare and contrast their findings to other studies. It appears that their study is nicely connected to other case studies (e.g., disappearing lakes) in Australia, India, and Aral Sea regions, albeit short-term time scale.

Answer: Thank you for the comment. In this case we take guidance from Sivapalan et al. (2012) who proposed three approaches for the conduct of socio-hydrology, i.e., historical socio-hydrology, comparative socio-hydrology and process socio-hydrology. This manuscript is an attempt at a historical socio-hydrologic case study. And yes, we do intend to do comparative studies in the future. For example, we have already considered comparing the TRB case with the Hai River (located in eastern China, including famous cities of Beijing, Tianjin, etc.). They share different historical development paths and different levels of social economy and we might find something interesting through such comparisons. Of course the comparison between Chinese and foreign cases like those in Australia, India and Aral Sea regions will also be interesting. However, there is much background work to do in each of these places before we can do comparative studies. Therefore we propose this be done as part of future research.

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6. Some statistics can be reported for better understanding how the internal and external drivers of human and water interactions are similar or different. What are possible connections between the rapid development in the east coast of China and changes in human-water interactions in the TRB? Any tele-connections? Since the changes in the socio-hydrology of the TRB can be affected by changes in other places, it might be worthwhile to include such information. For example, figure 6 shows growths in population and irrigated areas in the study area. Can the authors compare these growths with those at the whole China? What is the major driving force of increasing irrigation in the study area? Has there been any decline in irrigation areas in some parts of China as a result of rapid industrial growth (conversion of ag land to urban and industrial land)? Does the TRB export grains to other parts of China? The authors might consider including information on regional crop growth and compared those to population growth in China. Any statistics on fertilizer usages in the study area? How about changes in water quality?

Answer: In this paper we have only performed a qualitative analysis for TRB. The kind of data analyses that the reviewer is requesting will of course be useful, but this is clearly premature and beyond the scope of this paper. We will be very grateful if the reviewer can assist us in the data collection and quantitative analysis.

The idea of tele-connections is also interesting and we do agree that such tele-connections do exist between places due to trade and political connections. These tele-connections may be reflected in virtual water trade and regional or world scale politics.

As for the suggestions about the Fig. 6 (Now Fig. 7), they are beyond the scope of this paper. In this manuscript, we prefer to focus on the broad outlines of the co-evolution of coupled human-water systems in TRB over 2000 years. The paper is already too long and addition of more details may defeat the main purpose of this paper.

7. Some concepts are not well-explained and need to be elaborated. See my com-

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ments below.

Answer: Thanks for the comments. Please see the responses for detailed comments.

8. While generally well-written and easy to follow, grammar could be tightened. See my detailed comments below.

Answer: Thanks for the comments. Please see the responses for detailed comments.

Responses to detailed comments:

1. Page 12755. “sustainable human development”? Change to sustainable development of human society.

Answer: We have revised the words accordingly. Thanks.

2. Page 12756. What do you mean by “social productive forces”?

Answer: The “social productive force” is a comprehensively applied concept in Marxist philosophy to represent the ability of human society to exploit resources (both natural and social) to meet a societal need. More details could be found in Wikipedia entry under “productive force”: http://en.wikipedia.org/wiki/Productive_forces. To facilitate further reading, we add more explanation in the revised manuscript, see p. 4 Line 102-105.

3. Page 12758, line 1. Insert “the” before the river names.

Answer: Revised. Thanks.

4. Page 12760, last paragraph. Move this paragraph to later.

Answer: The last paragraph is to tell the readers the main contents in following 3 sections. We have shortened this paragraph, as presented in revised manuscript p. 7 Line 205-189. Now the paragraph reads as follows:

Therefore, in terms of the human-water relationship, in this paper we divide the co-evolutionary history of the SHS in TRB into three stages, i.e., the natural stage from C7442

around the 2nd century BC to the 18th century AD, the exploitation stage from the 18th century to mid-20th century and the degradation and recovery stage from the mid-20th century up until now. A detailed discussion of each stage will be presented in Sections 4 to 6 using the Taiji-Tire, a comprehensive organizing framework that is presented next.

5. Page 12762, line 26. Outmigration?

Answer: Revised. Thanks.

6. Page 12763, line 12. Change : week” to “weak”

Answer: Revised. Thanks.

7. Page 12763, line 19. Insert comma after “Road”

Answer: Revised. Thanks.

8. Page 12764, lines 1-2 It is unclear why the authors state “the city-states in TRB became more vulnerable to social and environmental stresses”. If they were more mobile than traditional agrarian societies, weren't they less vulnerable to internal and external stresses?

Answer: Our statement that the city-states in TRB became more vulnerable to social and environmental stresses is based on the notion that city-states are more stable if they can keep their locations when facing stresses. So actually we are talking about the SHS of a city-state, but not the city-state alone. If a city-state is very mobile, it will be appropriate to migrate to leave the former artificial ecosystem, which would then collapse without human maintenance. In order not to mislead the readers, we changed “vulnerable” to “sensitive” to express the meaning above. See revised manuscript, p. 14 Line 399.

9. Page 12764, lines 4-6, I don't agree that all social factors are internal drivers and hydro-climatic factors are external drivers.

Answer: We agree that the sentence construction is a bit awkward: we did not mean to say that all social factors are internal and all hydro-climatic factors are external. Actually, under a low level of productive force, hydrologic conditions (precipitation, evaporation, transpiration, runoff and their variations) are internal direct causes for the abandonment, whereas climate variations and resultant hydrological responses (not the hydrologic conditions), as well as the high mobility of society and other social conditions are long-term drivers. We regarded them also as external drivers because they did not directly affect the scales and contents of water consumption but provided a long-term influence on the internal factors. Anyway, we have corrected the sentence to avoid misunderstanding, as presented in revised manuscript, p. 13 Line 405-409. Now it read as:

The lower level of productive force and the higher mobility of society were the most important internal reasons for the abandonment of settlements in history, while the climate variations and the hydrological responses to these variations (which ultimately caused a shift of the river courses) functioned as external direct drivers, in addition to some social factors that operated at much larger scales.

10. Page 12765, line 14. What do you mean by “a deterioration of system sophistication”?

Answer: It means the system complexity decreased. We have rewritten this sentence to make the meaning more clearly in revised manuscript p. 15 Line 445-446.

11. Page 12765, line 22. Insert comma before “and”

Answer: We have revised the words accordingly. Thanks.

12. Page 12765, line 23. Change “In” to “With”

Answer: Revised. Thanks.

13. Page 12765, line 24. Change “Is” to “was”

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Answer: Revised. Thanks.

14. Page 12765, line 25. Change “are” to “were”

Answer: Revised. Thanks.

15. Page 12766. Can the authors demonstrate how “SHS evolved into a new equilibrium state”? This could be an important concept to be discussed in a conceptual framework.

Answer: In this case we were trying to explain why the peak of the settlement abandonments occurred in the 8th century AD when the climate had just turned into warm-wet. We gave two possible paths: one is the social reason (war and social unrest), the other one is natural, which could also be interpreted as a delayed effect. When climate became wet, more water may have discharged into the previously shrunken river, leading to frequent floods and causing disastrous consequences for the TRB society. This is a theory that could partly explain the unusual abandonments.

The SHS finally evolved into a new equilibrium state because after the natural disasters caused by floods due to climate warming and wetting, the societies will forced to find a suitable place to settle down and begin to adapt the social economy. Gradually, a new equilibrium, or a new SHS would appear. We have given more explanation in revised manuscript, p. 16-17 Line 488-494.

16. Page 12766. The second paragraph is repeated from the previous section. I suggest that the authors consider condensing information.

Answer: The second paragraph does not simply repeat the previous contents about the abandonment of the settlements. In this paragraph, we were trying to explain several interesting socio-hydrological phenomena to show how humans are affected by the dominant natural factors. So we were not just talking about the regulations of abandonments, but present further analysis about the underlying reasons and the resulting human-water relationships.

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However, we found that some sentences in this paragraph are indeed somewhat awkwardly written, and some information was indeed repeated. So we have condensed this paragraph and corresponding parts in other sections. See the revision in revised manuscript, p. 15 2nd paragraph and other revisions like that in p. 7 Line 189-210 (we have condensed this paragraph).

17. Page 12767, lines 2-3. Can the authors show the different patterns of human settlement development in the study area over time?

Answer: Before 1760, the population in TRB was basically around 300,000, as mentioned in Sect. 4.2. The human settlement showed a pattern of dozens of isolated city-states, especially during the Han and Tang Dynasties. When the population was high and the cities in the Western Region expanded with the development of agriculture, communication between city-states was more common. The human settlements showed a dual structure of urban and rural, which we say is a new city-centered pattern. More thorough discussion about the evolution of social pattern over time needs to be carried out, which is left for future research.

18. Page 12767, lines 15-16. I wonder if the extensive irrigation development and the resultant high water consumption could also lead to changes in the next phase of socio-hydrologic system. It seems that according to the Taiji symbol, both positive and negative components coexist in one system.

Answer: Yes indeed. Both positive and negative components coexist in one system and sometimes we need to understand the impact of some factors from a broader perspective. Of course irrigation development and the resultant increase of water consumption are relevant in the future socio-hydrological event because they constitute the fundamental conditions for future human-water interaction. It's like that we can never imagine that renaissance happened during the Middle Ages, but we can also never deny that the renaissance came out from the Middle Ages. So yes, we believe that the previous socio-hydrological behaviors will lead to changes in the next phase of SHS.

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The problem here is how and we are going to explore it in the future.

19. Page 12770, 2nd paragraph. This seems a nice place to illustrate how small fragmented local societies were connected to larger worlds through human-water interactions at different stages.

Answer: We thank the reviewer for his advice and we agree that broadening the study of human-water interactions will be interesting. However, we lack the necessary data for mapping and comparison. We plan to work on it to show how a single local-scale SHS connects with others if, for examples, it is merged into a larger regional scale SHS. This may help us understand all aspects of the SHS. In fact, we have already identified the three most important features of SHS, i.e., the vulnerability, the expansion and uncertainty (just a theory). The mentioned problem may help us to understand the expansionist instinct of the SHS. So we would not like to add discussion about the issue right now in this manuscript but keep it a problem that remains to be solved.

20. Page 12771, lines 15-18. Can the authors show declines in water quality in the study area as a result of fertilizer usage?

Answer: We have added an example to indicate the water quality decline due to fertilizer use, as presented in revised manuscript p. 21 Line 624-626. We added: The comprehensive pollution index of water quality at Alar section in upper Tarim River is 12.544 in 1998, indicating that the water was seriously polluted (Li et al., 2006).

Please note that we have added a new reference here, namely the Li et al. (2006), as presented in manuscript, p. 29 Line 868-869.

21. Page 12771, before section 5. This might be a nice place citing other references for comparative socio-hydrologic studies in Australia, India, and the Aral Sea.

Answer: We thank the reviewer very much for this comment and we have given our response for it above. Please see response for general comment 5. Thanks.

22. Page 12772, line 18. Remove "the" before lake names

C7447

Answer: We have revised the words accordingly. Thanks.

23. Page 12772, line 19. Insert “the” before TRB.

Answer: Revised. Thanks

24. Page 12772, line 20. Insert “the” before Kaidu-Kongqi River

Answer: Revised. Thanks

25. Page 12772, line 22. What do you mean by “during the natural period”?

Answer: The tenses in the sentences were wrong. The “is” should be “used to be”, the “lost” should be “had lost”. What we were trying to say is that the migration of Kaidu-Kongqi River happened during the natural period, namely before 18th century when humans were not the dominant factors in the SHS evolution. The natural period is referred to as the natural stage in the manuscript.

So except for tense corrections, we changed the “natural period” to “natural stage” to avoid confusion, as presented in manuscript p. 22 Line 662-664. Now the sentence reads as:

The wetting signal is strong in the Kaidu-Kongqi River, which used to be a source river for the Tarim River but had lost hydraulic contact with the mainstream of the Tarim River during the natural stage.

26. Page 12773, last paragraph. It seems that SHS did not evolve into a new equilibrium state.

Answer: No, it did not. After the historical analysis and deeper research about the current situations in the lower Tarim River basin, we believe that although the human-water relationship in this area has made significant progress and some measures are taken to repair the damaged SHS, the system is still not at an equilibrium state. The apparent recovery we experience now is not sustainable and a set of systematic measures need to be taken to change the mode of the socio-economy and human lifestyle.

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The water system, along with other relevant systems such as the ecosystems, need to be more carefully exploited.

27. Figure 6. Better to show population density rather than raw population for comparing two regions with different sizes.

Answer: In Fig. 6 (now Fig. 7), we are trying to illustrate the idea that the population was constantly increasing even during the social unrest period when the agricultural products and social welfare apparently were not supportive enough for large populations. We were not trying to compare the population between Hotan and whole TRB, we were trying to show the increasing trend of population was not a special case for specific area within TRB. The population density is not relevant for this discussion.

Reference:

Li, X., Pan, X., He, B., Wang, X.: Water quality assessment and ecological security research in main stream of the Tarim River, *Arid Land Geogr.*, 29, 653-657, 2006.

Sivapalan, M., Savenije, H. H. G., Blöschl, G.: Socio-hydrology: A new science of people and water, *Hydrol. Process.*, 26, 1270-1276, 2012.

Please also note the supplement to this comment:

<http://www.hydrol-earth-syst-sci-discuss.net/10/C7436/2014/hessd-10-C7436-2014-supplement.pdf>

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 12753, 2013.

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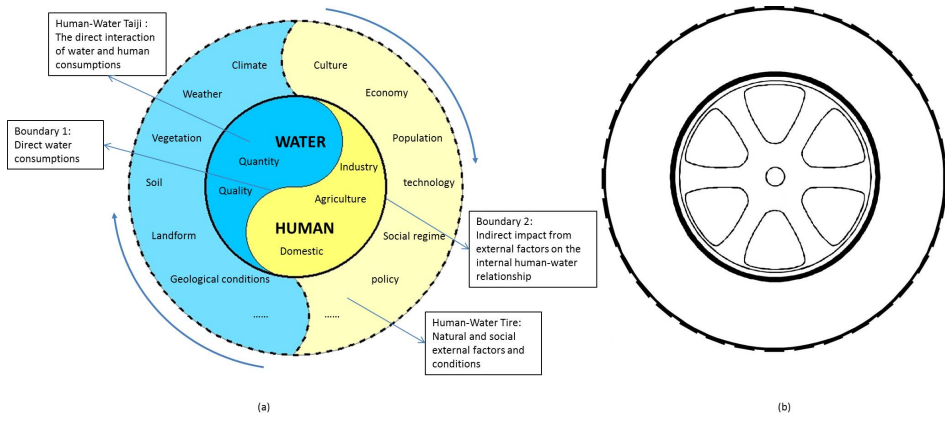


Fig. 1.