Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2019-389-AC2, 2020

Hydrology and Earth System Sciences
Open Access
Discussions

Interactive comment on "A novel data-driven analytical framework on hierarchical water allocation integrated with blue and virtual water transfers" *by* Liming Yao et al.

Liming Yao et al.

chenxudong198401@163.com

Received and published: 24 February 2020

The research entitled "A novel data-driven analytical framework on hierarchical water allocation integrated with blue and virtual water transfers" is interesting and provides some insights that can be used by the decision makers for taking sustainable decisions. However, the paper could be accepted for publication if the authors incorporate the following comments and suggestions in final draft.

[Comment 1.] Elaborate the disagreement point of the leader in the Stakelberg model.

[Response.] Thank you for your comment. We have provided additional information

regarding the disagreement points for better clarity in the Solution Procedure section.

First, we introduced the importance of defining a disagreement point. Combined with the bi-level Stakelberg model, there was an interactive process between the leader and followers. The leader possesses a higher priority to move first, and the followers play among themselves according to the Nash-Harsanyi equilibrium after observing the leader's announced strategy; then, the followers provide feedback to the leader. The leader then maximizes its objective function based on the identified best-response strategies of the followers. During the bilevel strategic interaction, with the decrease in sectoral vulnerability at the lower level, the water utilization efficiency of the system at the upper level will decrease to some extent. Once the solution is worse than the disagreement point, irrespective of whether it is for the leader or the competing followers, the decision maker can no longer accept it.

Second, we introduced the derivation of the disagreement point and the application in this paper. Gao & Lv, (1989) introduced the interactive satisficing trade-off method based on the tactics of the ideal point method, which helped to resolve problems including multiple conflicting objective functions. The ideal point was the situation in which the objective function reached its optimal value; however, in general, not all objective functions would reach the ideal points simultaneously. A set of ideal points was not in the feasible set, but rather each objective value would exist between the negative ideal point and positive ideal point. Previously, Hans and Eric, (1991) described how the disagreement point approach can be applied to bargaining solutions. Furusawa and Wen, (2002) analyzed the tariff trade war and pointed out that the disagreement point was regarded as bargaining frontier in the bargaining process.

As for the biobjective models (Gao & Lv, 1989), a solution that was simultaneously optimal for each decision maker's objective function rarely occurred among the bilevel problems involving multiple decision makers, because of conflicts among the leader and the competing followers. Hence, by utilizing the concept of the bargaining game and negative ideal point in this paper, we extended the definition of the disagreement point, namely, the disagreement point that presented the worst result, which the decision maker was unwilling to accept. Hence, additional constraints for each level were added for which each objective function value was better than the respective disagreement point.

Finally, combined with the practical problem described in this paper, we have defined the vector of the disagreement points as the maximum vulnerability to the followers and the minimum efficiency to the leader. To be specific, the disagreement point of each objective was calculated at page 11. References Gao, J., & Lv, X. Interactive satisficing trade-off method for multiobjective optimization (in Chinese). Journal of Hefei University of Technology, 1989, (2), 32-41. Hans P, Eric V D. Characterizing the Nash and Raiffa Bargaining Solutions by Disagreement Point Axioms. Mathematics of Operations Research, 1991, 16(3):447-461. Furusawa T, Wen Q. Disagreement points in trade negotiations. Journal of International Economics, 2002, 57(1):133-150.

[Comment 2.] I strongly recommend to explain the meaning of all variables and parameters for improving the readability of the paper.

[Response.] Thank you for the detailed comment. We have enriched Appendix A to explain the meaning of all variables and parameters in details (Please see the supplement file AppendixA.pdf). In addition, appendix B and C are given to elaborate the details of model proposal.

[Comment 3.] What are the termination conditions mentioned at Page 11? Please make it clear.

[Response.] The termination condition in each case is that when individuals stop evolving, that is, when the best solution (individual) of the current generation is the same as the previous generation or when the algorithm reaches one hundred iterations (Messias et al., 2016). Reference Messias, Valter Rogério, Estrella J C , Ehlers R , et al. Combining time series prediction models using genetic algorithm to autoscaling Web applications hosted in the cloud infrastructure. Neural Computing and Applications,

2016, 27(8):2383-2406.

[Comment 4.] Line 273, please revise the formation of reference citation.

[Response.] Thank you for the detailed comment, we have corrected the mistake and check the whole manuscript.

[Comment 5.] Variable unit is needed in each Table, such as Table 8.

[Response.] Thank you for the detailed comment, we have added the unit for each table.

[Comment 6.] Unnecessary reference lump should be avoid through the whole paper, such as "Generally speaking", cited references should have meaning.

[Response.] Thanks for your suggestion. We have read the whole paper again and enrich the descriptions for cited references and deleted some unnecessary references.

[Comment 7.] Conclusion section is a little lengthy and therefore needs to be shrunk. Too much information would distract people attention.

[Response.] Thank you for your suggestion. We have condensed the conclusion section in the revised manuscript following the layout including problem description, model, application results, comparative and sensitivity results, managerial insights and future research directions.

Conclusion

In this study, we proposed a novel model based on Stackelberg-Nash-Harsanyi game theory for analyzing the water reallocation problem in the promise of water transfers and crops transactions. To describe realistic water allocation, withdrawal and transaction processes, this paper employed a bilevel framework with one leader and multiple followers, where a water affairs bureau was in the leadership position and multiple water usage sectors were in a lower position. Vulnerability, including the destroying degree (caused by deficient water withdrawal) and economic loss (caused by excess water withdrawal), is the lower level objective. In addition, the water utilization efficiency was maximized at the upper level across the whole system.

Blue and virtual water transfers are examples of mechanisms that essentially relieve uneven distribution of water. In this study, one incorporated idea is that the blue water can be reallocated to industrial and domestic sectors to develop water-saving agriculture. The other incorporated idea is that the virtual water existing in crops is quantified to optimize inter-regional exports and international imports. Virtual water transfer path is from regions defined by comparative advantage of water resources to those defined by comparative disadvantage of water resources so that water utilization efficiency was improved for the regions involved. Besides, blue water transfer path is from sectors with lower water vulnerability value to those with higher water vulnerability value so that vulnerability caused by exceed/lack the quantity of water demand decreased for the sectors involved. All told, having incorporated the concepts of blue and virtual water transfers, our model is able to further relieve the water scarcity stress as well as reduce the vulnerability and increase the water utilization efficiency. During the dynamic strategic interaction, the leader modifies its decision based on the best-response strategies by the followers.

To verify the feasibility and practicality of the developed model, a real-world application was conducted in the Hetao irrigation district. The results found that water demand in the domestic sector was first satisfied, followed by that of the agricultural and industrial sectors; blue water transfer provided an opportunity for each sector to achieve an efficient utilization of water, and virtual water transfer provided a new opportunity for water conservation and land saving. To be specific, some initial water rights were transferred from the agricultural sector to the industrial and domestic sectors, and key crops, particularly water-intensive crops (e.g., wheat and sunflower), were imported from other countries rather than being grown domestically.

Furthermore, to demonstrate the superiority of the developed model, two comparative scenarios were considered: one without virtual water transfers and the other limiting

blue water transfers. The analysis of Scenario A highlighted the importance of virtual water transfers in significantly alleviating water usage stress. Furthermore, the analysis of Scenario B verified that blue water transfers reduced vulnerability in each sector and demonstrated how inter-regional exports, international imports and blue water transfers can result in higher water utilization efficiencies in all three sectors.

Considering the changing environment and water-saving strategies, several scenarios were assessed, including one without any change (the results of the proposed model). Faced with varying water availability, it was concluded that in wet environments, crops with more virtual water could be planted and exported. In contrast, in dry environments, crops that require more irrigation should be imported.

An analysis of how to reduce water demand in different water usage sectors is discussed. The results found that blindly decreasing domestic water demands can harm efficiency and increase vulnerability even though this kind of strategy can reduce total consumption in the water allocation system. When industrial water demand decreased by 10\%, the overall efficiency showed improvement; however, too great of a reduction could result in a negative influence on the sustainability of the water allocation system. With a decrease in agricultural water demand, water utilization efficiency improved, and total consumption decreased. However, if there is a very large reduction, the industrial sector vulnerability would be aggravated.

Hence, several policies can be implemented in terms of various sectors to alleviate the regional water stress and the negative impact caused by the crop trade, as well as to safeguard regional food security to develop a sustainable irrigation district.

Further, under the changing market in terms to crop transaction price and water transfer price, several scenarios were conducted to probe deeper the optimal allocation and transfers strategies. The results denoted that the model was more sensitive to available water and sectoral demand, instead of crop import price. Further, the model was more sensitive to water price variation in maize, followed by wheat and sunflowers. Then the fitted smoothing lines based on the solved values implied that the price elasticity of water transaction is not linear, which gave a direction for formulation demand function in future research.

This work focused on water allocation in a bilevel framework. Given that we explored only one leader and multiple followers, there are possibilities for multiple leaders and multiple followers in future research. Furthermore, a dynamic analysis from the time perspective may be interesting.

[Comment 8.] Personally, I would like to see some more elaboration on managerial insights. What kind of problem can be solved by the proposed model? Whether the results are able to offer some suggestions on future water management in real-world practice.

[Response.] Thank you for your question. We give the following explanation.

In many places, including the north of China, there are two different hierarchical structures, the water affairs bureau and the water usage sectors, within an irrigation area. Against the backdrop of water scarcity, incommensurable conflicts exist among different water users and the water affairs bureau because of differing objectives. Additionally, faced with multiple followers, another main problem is that various water usage sectors, such as agricultural, industrial, domestic and ecological sectors, compete for limited water resources. At present, there is very little literature on irrigation districts that take into account blue/virtual water transfers and water allocation simultaneously within a bi-level framework. Due to the unsuitability of this problem for modeling by conventional methods, a novel game model is presented considering the water allocation and blue/virtual transfers together, in view of the hierarchical structure of the problem.

Based on the conceptual framework, this paper has proposed a novel game model based on Stackelberg game and Nash-Harsanyi equilibrium models to analyze the one-leader multi-follower problem, including the water affairs bureau and sectoral water users in water resource management systems. In this way, the water affairs bureau

possesses a higher priority to decide the initial water allocation rights, and the followers play among themselves according to the Nash-Harsanyi equilibrium after observing the leader's announced strategy and provide feedback to the leader. The leader then maximizes the system's water utilization efficiency based on the identified best-response strategies of the followers. The process proceeds with the interactive Stackelberg game as well as the Nash-Harsanyi bargaining model. Finally, through a strategic interaction, an optimal solution can be gained.

Being a water-scarce area, the Hetao irrigation district is still a grain exportation area with a large amount of output. Since the reform and opening-up, China's crop production center began to shift from the originally developed southern and eastern regions to the economically backward northern and western regions. Additionally, crops imported from other countries, accompanied by virtual water transfers, have become another measure to relieve the local water scarcity pressure. However, in previous articles, scholars have ignored that a great amount of crop imports would lead to a decrease in local production, which could significantly reduce the income of local farms. Hence, this paper endeavors to formulate a strategic plan by employing virtual water to reduce crop water demands jointly with blue/ green water irrigation systems.

By incorporating virtual/ blue water transfers into the above proposed model, three realistic problems can be solved: (1) optimizing the water withdrawals in agricultural, domestic and industrial sectors and determining the irrigation requirements for different crops in a planning year; (2) optimizing the virtual water (existing in crops) quantities to be imported and exported, and (3) optimizing the blue water quantities to be transferred from the agricultural to non-agricultural sectors.

We applied the developed model to a real-world practice to acquire more information on water saving, land planning and sustainable development. In addition, It can be applied to any water resource system not only in the Hetao irrigation district but also in other areas with similar problems.

The managerial insights derived from results of the case study are showed as follows:

(1) crop consumption in this district is far less than that produced, particularly for sunflowers. The surplus crops could be sold to south China.

(2) Pressure on regional water resources was relieved, regional food security was safeguarded and planting land was appropriately utilized. According to the results, the total land use for crops was reduced by 16.7% due to the international imports; further, the total virtual water in the imported crops was calculated as 4.16×109 m3, which would save 75.64% of the total available water in the area.

(3) The negative impact caused by the crop trade was alleviated, and the potential water saving strategy was fully explored. According to the results, after considering agricultural blue water transfers and virtual water transfers, an increase in the water resource system efficiency and a decrease in vulnerability values were found in each sector, as shown in Table 4.

Hence, the above analysis suggested that when there was insufficient water, blue water could be transferred to the industrial and domestic sectors from the agricultural sector to enhance the water utilization efficiency and achieve greater economic benefits.

(4) Furthermore, to provide more information to decision makers, we conducted the following work.

First, the domestic sector with the value of 0.254 seemed to be the direct reason for water stress in this district. Before drawing up a long-term future water plan, the determination of which sector was the largest contributor to regional water stress is of great importance.

Second, virtual/ blue water transfers were verified to be beneficial for both hierarchical decision makers, for which the results are shown in Figs. 8-10 and Table 6. Compared with Scenario A limiting virtual water transfers, the total water consumption of the proposed model decreased from 4,547,691,062 m3 to 4,446,716,331 m3; the blue water

transfer value was reduced from 1,126,120,905 m3 to 1,085,970,257 m3. Compared with Scenario B, the total water consumption solved by the proposed model increased from 4,327,537,703 m3 to 4,446,716,331 m3, with the most water being consumed by the domestic sector rather than the agricultural sector, which implied that there was a positive effect propelling the water utilization efficiency and reducing the sector vulnerability when blue water transfers were considered.

Third, scenario analysis was conducted to cope with the water management strategy under climate and hydrological changes. Table 8 shows the solutions to the decision variables under the varying available water constraints. The analysis also demonstrated that industrial vulnerability is the least sensitive to changeable climate change, followed by the agricultural sector, with the domestic sector being the most sensitive. Overall, the domestic sector should be paid more attention regardless of the presence of extreme dry or wet conditions, as the sector is more sensitive to the available water.

Furthermore, with a decrease in available water, the import trade increases, and with an increase in available water, there is an increase in the export trade, particularly in sunflower exports (a crop that provides higher economic benefits with greater water consumption). Hence, in a wet environment, crops that contain greater virtual water are suggested to be planted and exported; in a dry environment, it is suggested that crops that require more irrigation be obtained through import trading.

Fourth, to regulate water saving precisely, several sensitivity analyses were conducted to address the purpose of water saving in different sectors, which provided insights into future investments into water conservation and sustainability development. In addition, by using an Extended Fourier Amplitude Sensitivity Test (EFAST) method, we found that the proposed model was less sensitive to the import crop prices than to the available water and sectoral water demand.

Overall, under the bi-level framework, individual and system benefits can be balanced. In addition, measures solved by the proposed mode have a greater capacity to alleviate the pressure on regional water resources, safeguard regional food security, alleviate the negative impact caused by the crop trade and develop a sustainable irrigation district.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-389/hess-2019-389-AC2-supplement.pdf

---

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2019-389, 2019.