On the Application of Agent-based Model on Water Allocation to Improve Water Usage Efficiency and Reduce Conflict

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Abstract

Water allocation using physical model coupling with management layer in which cooperative role playing game theoretic approaches and has been utilized to investigate how the net benefits can be fairly reallocated to achieve optimal economic reallocation of water resources. An integrative, interactive water allocation model, crop water demand calculation and an agent based model using input from physical model has been constructed. Initial model running for crop season 2015 shows that show that with the scenarios "business as usual" results in the highest potential conflict value (0.446) while the "negotiation between adjacent sub-districts" results in lowest in potential conflict value (0.285) which encouraging the cooperation in water allocation along the distribution canals of irrigation district. Therefore, negotiation and exchange of the water uses between user groups, irrigation schemes in the irrigation district needs to be recognized, facilitated and institutionalized in the administrative procedure in the future time when there will be more conflicts with regards with the decrease in water availability.

Key words: Agent based model, water allocation, and water use conflict

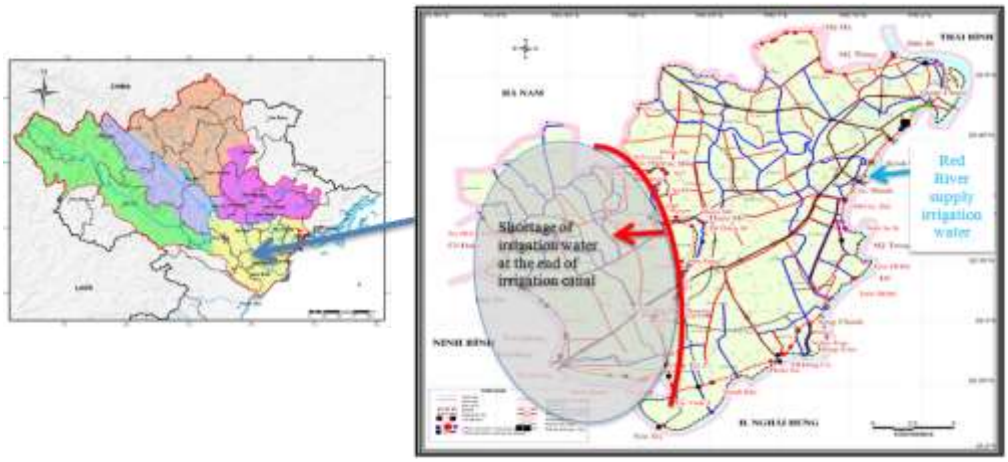
Introduction

Water resources management in an equitable and sustainable way is intrinsically complex. This is due to the fact that the scale of management implied by hydrological characteristics often comprises layers of social, managerial, and economic institutions. Even at the sub-basin level there may be many users such as local small-scale farmers, large-scale commercial farmers, hydro-electric power companies, industrial users, municipal water users, and those using water resources for leisure or tourism.(1) While the underlying purpose of water allocation – that is, sharing available water resources – has not changed fundamentally, some of the key considerations driving water allocation and planning have evolved significantly over time. This implies that the focus of water allocation and planning has also been shifted substantially, with a greater focus on demand management and on optimizing the use of existing supplies. This in turn led to changes in governance structures for water resources management which often characterized by overlapping national, regional and local regulatory frameworks and authorities involving classical problems of collective action.(1, 2)

The study area is the North Nam Ha irrigation district located in the Red river basin - Vietnam (figure 1). The irrigation system is surrounded by 4 rivers Red river, Dao, Day and Chau Giang River, with Red river is the main water supply for the irrigation district. The whole system is a mixed of high ground and subsidence basin with rich soil to support the agricultural system, the total area of the irrigation district is 100.261 hectares with non-agriculture area accounts for about 37% of the area. The water extracted from the canal by the farmers is used to irrigate the number of fields determined by themselves or the authority at the beginning of each season. During the crop growing season, farmers irrigate their fields as it needs (determined by the availability of water and the experience or mostly following the schedule of the irrigation operator). If the amount of water actually reaching the fields is less than the amount needed to irrigate the given number of fields, then water stress occurs and accumulates over the season. Surveying of the irrigation district and discussion with stakeholders has revealed the following problems with the water management and water allocation scheme of the area as following:

- Years of land use and crop pattern change without consideration to the capacity of the system to supply water has led to lack of water at area of cultivation, especially at the ends of the irrigation canal;
- Inefficient water use within the irrigation system;
- Water user groups are largely disconnected;
- Lacking a coherent interaction between the irrigation system management and stakeholders.

Figure 1. Map of North Nam Ha irrigation districts in Red river basin in Vietnam(3)



Water allocation and resources management studied has been carried out as a decision support system for many river basins in the world,(4) starting with simple simulation and analysis of various water allocation scenarios and, above all, scenarios of users' behavior in Olifants river basin of South Africa (5) using WEAP modeling package.(6) The adoption of water demand management from scenario simulation procedures offers opportunities for remedying the water shortage for different user groups. Water allocation modeling approach has been proven to be reliable tools for decision makers and users to appropriately plan their water allocation activities. When sufficient experience has been achieved using water allocation for water resources allocation between regions and user groups, there was other pressing issue with water allocation model application as how the model can incorporate water management scheme for ecological assessment.(7) Therefore, the water resources model beside addresses the water demand from user groups also need to takes into account the water needs of the ecosystem to assist in the evaluation of tradeoffs in water allocation and the determination of ecosystem restoration goals.

In Viet Nam, water allocation model has been used occasionally to address the water distribution problem for specific river basin such as Dong Nai river basin(8) or Mekong basin.(9) In which the research has developed an aggregate economic hydrologic model for the basin that allows the analysis of water allocation and use under alternative policy scenarios. The same methodology has also been applied to Maipo river basin in Chile.(10) The development of an integrated framework of analysis can be a first step to overcome some of the obstacles to effective management and joint cooperation in the Mekong River basin. It could also facilitate the upcoming negotiations of water allocation rules in the lower basin and thus contribute to the reasonable and equitable utilization of Mekong River water.

However, those applications employed classical water allocation models still show some shortcomings in addressing water allocation in a dynamic situation where the users face with cooperative and non-cooperative decision as well as a multi-criteria decision system.(11) Thus, it entails the development of next generation of water allocation model in which cooperative game theoretic approaches and participatory multi-criteria decision support under uncertainty are utilized to investigate how the net benefits can be fairly reallocated to achieve optimal economic reallocation of water resources. This methodology has been applied to the South Saskatchewan River Basin in Canada (12), Spree River basin in Germany(13) and showed that the model can be utilized as a tool for promoting the understanding and cooperation of water users to achieve maximum welfare in a river basin and minimize the potential damage caused by water shortages.

The ABM model approach falls in this new development trend of water allocation model system. Due to the hydrological and socio-economic complexity of water use within river basins and even sub-basins, it is a considerable challenge to manage water resources in an efficient, equitable and sustainable way.(14) The use of this new approach broadens the spatial information of actors in the process, revealing inter-connected topics not taken into consideration in earlier approach. This makes it possible to remain relevant, despite the sometimes rapidly evolving stakes, thus, ABM is a promising approach to better understand the complexity of water uses and water users within sub-basins. This approach is especially suitable to take the collective action into account when simulating the outcome of technical innovation and policy change.

As water resources management become more stressed, more precise specification of water availability and improved mechanisms addressing allocation under variability are crucial to preventing conflict and negative environmental impacts at the same time maximizing available supplies.(15) The application of agent-based modeling (ABM) approach is particularly well suited to capture the complexities of water resource management described above. (2, 10, 16) ABM makes it possible to couple sub-models for water budget, crop growth, economic decisions and water user interaction within an integrated modeling framework. The specific strength of ABM is that this approach can represent institutional relations among water users (water use priority, water rights), enabling us to fully capture the phenomena such as collective and cooperative action.

Agent-based modelling offers a potential insight to the processes configuring the water allocation and institutional water management rules. The purpose of the model is to simulate the behavior of actors (e.g. farmers, authorities) by setting up rules describing their decision-making and thereby contribute to an understanding of the processes creating the cooperative or non-cooperative water management scenarios. This understanding is not only interesting from a pure academic point of view but also an insight in how people act, and the resulting impact on the water allocation and availability can also be useful in a policy context. The agent-based modeling (ABM) approach is first validated at a research location in RRB North Nam Ha irrigation district for the purpose of harmonizing water allocation for irrigation, industry and environmental flow preventing salinity intrusion.

Materials and methods

Agent-Based Model for the sub-irrigation areas were modeled using CORMAS model (Common Pool Resource and Multi Agent System) (http://cormas.cirad.fr/indexeng.htm) based on the multi agent system built through the participatory discussion with the irrigation district operators and enable the co-development of a following management and behavior rules for the system taking account the future direction of the irrigation system. The ABM model was created in cell with each cell represents 0.25 hectare and the system is connected by irrigation canal with water distribution nodes.

Figure 2: Representative of the ABM model and interface between management sphere and physical sphere.

After setting up the ABM model, the role playing games were implemented in some of the sub-district in the irrigation scheme to gather the important water allocation practice and co-design the water allocation rules for the model. The participants were representative of irrigation district operators, water user groups and farmers. The water allocation rules have been carefully discussed and chosen as following:

- Direct interactions for service or information exchanges
- A sub-district which has the water intake may allow another sub-district, whose plot is along the same watercourse, to take water at the same time.
- A sub-district reduces a water use ratio will be compensate by the water user group by a reserved ticket (the right to use water at a high demand season).
- A sub-district converts some production plot to less intensive water crop will have the right to exchange water use ticket for other sub-districts.
- interactions through the irrigation scheme
- Rotation in the priority use of water for group of users at the head and end of the irrigation canal.
- When a sub-district along the canal takes water, another sub-district further downstream may be able to take half the required water volume.

The underlying physical model of water availability in the system was carried out using MIKE NAM model. The inputs for the basin are: rainfall data, daily evaporation. The output of MIKE NAM models are water flow according to each individual irrigation districts. For the individual district, water balance calculation considered total generated flow of the canals, streams in the district internally. Each individual district using specific close-by rainfall gauge data:

- Vụ Ban, My Thanh, Y Yen irrigation schemesusing Nam Dinh, Vu Ban and NinhBinh rainfall data.
- Nam Ninhirrigation scheme using Nam Dịnhand Truc Phuong.

- Xuan Thuy irrigation scheme using Truc Phuong, Giao Thuy and Ba Lat rainfall data.

Water availability at each irrigation scheme was updated for the management layers daily through direct input and output connection. And in reverse once there is a new management decision, the water availability and allocation model re-calculate the water for each irrigation scheme and notify whether the management satisfies water demand on the field through calculation of water demand for each unit cell.

One coefficient was proposed to measure quantitatively the potential conflict Pc can be described as the percentage of the area meet water requirement over area with insufficient water supply over the crop cycle of the district. This factor ranges from 0 to 1 with 1 being the highest conflict level.

Table 1: The water allocation scenarios used in the study

No	Water allocation scenarios
1	Normal operation (business as usual)
2	Equally distributed between sub-districts
3	Distribution with weighting factor according to the location along the canal system
4	Distribution with direct negotiation between adjacent sub-districts

Results and discussion

The example results of irrigation water demand according to frequency of satisfying the needs at 85% was calculated for crop season in the typical month of February 2015 using FAO guideline using Cropwat model as following:

Table 2: Irrigation water demand for crop season 2015

Crop	Irrigation water demand (m^3/ha)
Spring rice crop	6230.02
Spring vegetable crop	1512.33
Autumn rice crop	3397.54
Autumn vegetable	627.90
Winter vegetable	968.02
Perennial	1645.71

These type of irrigation water demands from crop has already reflect the Evapotranspiration and other losses, these data will be updated weekly according to the historical weather forecast and growth phase of crop for the management layer and user to make decision. From these irrigation water demand calculation and water availability at each irrigation scheme, a typical water allocation capacity of each scheme will be prepared as following.

Table 3: Water allocation capability for each irrigation scheme in North Nam Ha irrigation scheme

Irrigation scheme	Area	W need (m^3)	W allocate (m^3)	W deficit (m^3)
		13,795,661	12,416,095	1,379,566
Vuc Hau scheme	1,140	2,363,904	2,245,709	118,195
Dap Moi scheme	3,012	6,245,683	5,558,658	687,025
De scheme	317	657,331	525,865	131,466
Co Dam scheme	7,990	16,568,064	16,402,383	165,681
Nham Trang scheme	2,190	4,541,184	1,816,474	2,724,710
Coc Thanh scheme	10,721	22,231,066	22,231,066	666,931
Nhu Trac scheme	960	1,990,656	199,066	1,791,590

From the aggregate water deficit calculation, it shows that almost all of the irrigation schemes suffered water deficit during sometime of the growing cycles with Nham Trang irrigation scheme being the worst situation in water deficit. In the meanwhile De, Co Dam and Vuc Hau scheme are the least affected area. The reason for that is because some unbalanced water allocation happening with the schemes at the beginning of the distribution canal enjoys most of the water allocation demand for its commanding area leading to the deficit in water flowing downstream on the same canal.

Table 4: The initial calculation of Pc value for crop season in 2015

Scenarios	Aggregated water shortage area (%)	Pc coefficient value
1	44.67	0.446
2	37.10	0.371
3	33.18	0.331
4	28.45	0.285

Simulations result and calculation of Pc value for all the proposed scenarios listed in Table 4 show that with the scenarios "business as usual" results in the highest potential conflict value while the "negotiation between adjacent sub-districts" results in lowest in potential conflict value which encouraging the cooperation in water allocation along the distribution canals of irrigation district. The scenarios suggesting the weighting factor for different irrigation scheme based on its location along the canal and the equally allocation of water result in middle value of potential conflict suggesting that a middle ground on water allocation with little intervention from management operators could also result in better performance of the system in term of reducing potential water related conflict.

Conclusion

Participation in irrigation management and planning has been introduced to Vietnam for the recent decades, which often dealt with the setting up of the water user group and the working mechanism of the group. It has been shown improve the service of the irrigation system as well as the participation of the farmers in the operation and maintaining the irrigation works. However, institutionalize the operation as well as the negotiation process in time of water scarcity and conflict has not been introduced from the guiding order and circular. It necessitates the needs to facilitate the practice and example of the agent based model in the water allocation scheme like North Nam Ha irrigation scheme as a pilot case study for the irrigation. In setting up the logical and trading rule for the system on top of the current water allocation scheme, the agent-based model has been shown some increase in the total area irrigated without the structure measures (building more pumping stations and canal system). The first suggestion in cooperative measures and the negotiation process is the localization of the needs and demands in the area easy to serve and exchange some value to the areas that difficult to serve. The second suggestion from the model is the consecutive water intakes from the end of the canal up to the beginning to guarantee the water level at the water intake structure as well as limiting the unnecessary decrease in hydraulic water head at the end of the canal. Finally, with the negotiation and exchange of the water uses between user groups in the irrigation scheme, this behavior needs to be recognized, facilitated and institutionalized in the administrative documents in the future time when there will be more conflicts with regards with the decrease in water availability.

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