Agent-based modeling to facilitate resilient water management in Southeast and South Asia

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Abstract

Water is used and managed by stakeholders at different levels for diverse objectives, therefore understanding decision making and supporting coordination is crucial in achieving resilient water management. Companion Modeling (ComMod) is an interactive process facilitated by evolutionary models for knowledge generation and exchange, and for supporting collective decision-making. Role-playing games and computerized multi-agent simulations for focused group debates are complementary tools combined in a ComMod cycle and used at the field workshops. Agent-based modeling is used to understand how different processes in direct competition are coordinated, and to mediate the collective search for acceptable solutions to conflicting parties facilitated through exchanges. This paper compares the process of agent-based modeling applied in eight case studies with diverse natural and socio-economic conditions and different resource management problems in Bhutan, Thailand and Vietnam to show the creative thinking in developing and applying flexible ComMod modeling tools and provide lessons for their use in other situations.

Media grab: Even under diverse conflicting water management situations with very different bio-physical and socio-economic conditions, agent-based modeling can be flexibly applied for generating and exchanging knowledge and to facilitate collective decision-making.

Introduction

Water is a resource used for diverse purposes: agricultural production, fisheries and aquaculture, transport, tourism, drinking water, etc. It is widely recognized that inadequate coordination among stakeholders leads to inefficient water use, economic and environmental damage, negative externalities and social conflicts. Companion Modeling (ComMod) is an interactive process facilitated by evolutionary models to support dialogue, shared learning and collective decision making in resilient water management (Bousquet et al., 2006). Key complementary analytical tools combined in a ComMod cycle and used during field workshops are conceptual models, role-playing games (RPG), computerized agent-based models (ABM) with focused group debates. The modeling approach is applied for two objectives: (1) to integrate knowledge for understanding how different processes in direct competition are implemented by different stakeholders; and (ii) to provide tools for mediating the collective search for acceptable solutions to conflicting parties facilitated through exchanges. Eight case studies (Figure 1 and Table 1) are being implemented under the PN25 project of the CPWF which deals with conflicts regarding water sharing and social tensions over water use in Bhutan and Northern Thailand (Gurung et al., 2006, Barnaud et al. 2006, 2007; Dumrongrojwatthana et al., 2007), conflict between agricultural intensification and labor migration in Northeast Thailand (Naivinit et al., 2007), and conflict between rice and shrimp producers in the Mekong Delta, Vietnam (Dung et al., 2007). This paper compares the agent-based modeling processes developed in these case studies to illustrate how they are flexibly applied in diverse ecological and socio-cultural conditions for different land and water management problems.

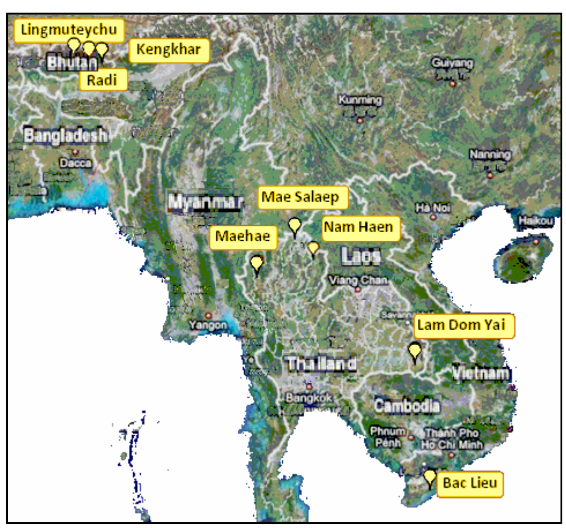

Figure 1. Location of the eight case studies.

Methods

Companion modeling (ComMod) is an approach to improve coordination processes at the watershed level among an increasing number of diverse stakeholders using common water resources (Bousquet et al. 2006). It uses various tools in a participatory way to generate a common vision of optimal resource use among stakeholders, and to identify and examine new resource-sharing scenarios. Two key tools used in ComMod are Role Playing Games (RPG) and Agent-Based Model (ABM). RPG and ABM are usually coupled in agent-based participatory simulations, but they can also be applied separately.

Table 1. Characteristics of the eight study sites.

Site	Location	Catchment / Basin	Area (km2)	Population density (persons/km2)	Main land use types	Main research objectives*
1. Lingmu-teychu	Punakha, Bhutan	Punatshang Chu, Bhramaputra	34	24	Irrigated wetland	Improve irrigation water sharing for rice cultivation
2. Radi	Trashigang, Bhutan	Gamri Chu, Bhramaputra	54	111	Rice, yak & cattle herders	Develop strategies to address grazing land conflict
3. Kengkhar	Mongar, Bhutan	Kurichu, Bhramaputra	156	12	Dryland farming	Promote sharing water from spring ponds
4. Mae Salaep	Chiang Rai, Thailand	Mae Chan, Chao Phraya	3	83	Maize, lychee, green tea	Promote sharing irrigation water
5. Nam Haen	Nan, Thailand	Nam Yao, Nan, Chao Phraya	106	7	Maize, orchards & forestry	Facilitate communication among villagers and Nanthaburi National Park
6. Maehae	Chiang Mai, Thailand	Ping, Chao Phraya	32	94	Rice, vegetable, orchards	Stimulate collective learning for land and water allocation
7. Ban Mak Mai	Ubon Ratcha-thani,Thailand	Lam Dom Yai, Mun, Mekong	1,680	119	Rainfed lowland rice	Understand interactions between land-water use and labour migration
8. Bac Lieu	Bac Lieu, Vietnam	Mekong Delta	2,600	269	Rice, shrimp, fish, crab	Analyze farmers' decision-making in rice & shrimp production

Notes: * More details and results from some case studies are presented in other ComMod papers at this conferences.

In a RPG participants are assumed to represent "fictional characters" and collaboratively create the stories close to their actual situation on the farm. Participants determine their actions based on their characterization, and these actions succeed or fail according to a formal system of rules and guidelines. Under this PN25 project, RPG is used as a social learning tool for researchers and players to exchange information for better knowledge on the ecological system and human behavior, and also to facilitate discussions, dialogues and negotiation in water resource management.

In an ABM, a system is modeled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules, for example, producing certain crops or selling certain products based on expected incomes. An important characteristic of ABM is the potential asynchrony of the interactions among agents and between agents and their common environment having its own ecological dynamics. For example, in Bac Lieu case, rice farmers and shrimp growers are interacting in an tidal effect area under different weather conditions in each year. With the help of a computer, interactions between agents can be repeated to explore the dynamics of the system.

Although RPG is a useful tool that allows multiple stakeholders to interactively examine the complexity of the systems that they are part of, in operation it is costly and time consuming, cumbersome setting up, slow in simulating new scenarios and difficult to analyze its results. To overcome these constraints, an hybrid ABM-RPG can be built as a ABM but similar to the RPG in its features and rules, which is far more time-efficient and less costly to simulate scenarios. This hybrid model can run interactive simulations in which some of the decisions are taken by real participants, while others are taken by artificial agents (Barnaud et al., 2007). However, RPG is usually needed at the beginning for stakeholders to understand what the ABM will simulate.

Comparative analysis and discussions

The following discussions are based on the agent-based modeling processes in eight case studies summarized and compared in Table 2. Among these cases, six have the objective of facilitating collective decision-making (C) but all aim at a better understanding of the study systems through knowledge generation and exchange (K). However, in the three cases of Radi, Mae Salaep, and Nam Haen, local stakeholders and researchers already knew better than in the other cases about the conflicts, therefore a platform for communication and negotiation is focused. On the other hand, in the Ban Mak Mai and Bac Lieu cases (without C) knowledge on stakeholders' decision-making is needed first. With improved knowledge, agent-base modeling is expected to be applied also for collective decision (C) in the Bac Lieu case.

RPG (G) were used in all eight cases as a main modeling tool for both knowledge generation and exchange (K) and/or to support collective decision-making (C). However, in the Radi and more recent Kengkhar cases, neither ABM (A) nor hybrid model (H) were applied yet. In Radi, the process is temporarily stopped after the RPG because of the legal and institutional complications in dealing with conflicts in using grazing land between rice growers and herders living in two parts of the watershed. In Kengkhar, where coordination for sharing water is needed, the process is starting and an hybrid ABM-RPG will be developed. ABM (A) and/or hybrid model (H) were applied in 6 cases to explore scenarios in participatory simulation sessions. In the

Mae Salaep case an hybrid (H) was used after the RPG (G) to explore the effects of new water allocation rules on lychee and tea farms, and in the Nam Haen case an hybrid model (H) was developed to communicate the outputs of the gaming sessions to more villagers and the national park officers.

Table 2. Agent-based modeling tools applied in the eight case studies.

Site	Objec-tives	Tools	Spatial dimension	Temporal dimension	Active agents	Interac-tions	Model components	No of sessions
1. Lingmuteychu	K C	G A	Fi, Fa, Vi, Ca	G: Annual, 3 years A: Annual, 10 years	Farmers, Village administrators	E C	Water flow Rice production Information exchange	G: 3 + 1 training A: 8
2. Radi	(K)C	G	Fa, Vi, Ca	G: Annual , 5 years	Farmers	E C	Livestock Land degradation	G:1+ several with small groups
3. Kengkhar	K C	G	Fa, Vi	G: Annual , 6 years	Farmers	E I C	Water tank Household water use	G: 1
4. Mae Salaep	(K)C	G H	Fi, Fa, Vi, Ca	G, H: Annual , 5 years	Farmers Village representative Religious leader	E I C	Crop, farm, slope Irrigation channels Small reservoirs	G: 2 H: 1 + several with small groups
5. Nam Haen	(K)C	G H	Fi, Fa, Vi	G, H: Annual , 2-5 years	Farmers Village leader National Park Royal Forest Depart.	E	Crop Non timber forest products	G: 2 H: 2 G+ A: 1 + teaching tool
6. Maehae	K C	G A	Fi, Fa, Vi, Ca	G: Seasonal, 4 years A: Monthly, 9 years	Farmers Foresters Community Network	E I C	Forest Crop Water	G: 4 A: not yet.
7. Ban Mak Mai	K	G A	Fi, Fa, Vi	G: Daily , 1-2 years A: Daily , 10 years	Farmers Village	E I C	Hydroclimatic module Household module Rice module	G: 3 A: 3
8. Bac Lieu	K	G A	Fi, Fa, Vi, Ca	G: Monthly , 2 years A: Weekly , 5 years	Farmers Water manager Middleman Seed provider	E C	Rice, shrimp Water salinity Household budgeting	G: 4 A: 2 (planned)

Notes for columns:

- Objectives: K = knowledge generation and exchange, C = collective decision (communication, negotiation)
- Tools: G = Role playing games, A = Agent-based model, H = Hybrid (combined G and A)
- Spatial dimension: Fi = Field, Fa = Farm, Vi = Village, Ca = Catchment
- Temporal dimension: time step (annual, seasonal, monthly, weekly, daily) and time horizon (no. years)
- Interactions: E = via environmental factors, I = peer to peer interaction, C: collective within group
- Number of sessions: how many sessions with local stakeholders or for other purposes as training, teaching were organized.

In the spatial dimension, the farm (Fa) and village (Vi) levels were considered as important in all eight cases. The lower and higher levels, field (Fi) and catchment (Ca), were included in six and five cases, respectively. So, under this PN25 project the applications of agent-based modeling are focusing on water use conflicts among farmers at the village level, but when needed they also include lower or higher levels.

In the temporal dimension, five cases applied the time step of one year, but the time step in the three other cases were shorter, from daily in the Ban Mak Mai case to reflect the detailed crop calendar, to monthly/weekly in the Bac Lieu case to simulate the salinity variation, and to seasonal/monthly in Mae Hae to describe the forest management. In most of the cases, the same time step was applied in both RPG and ABM or Hybrid, except in the Maehae and Bac Lieu cases, thanks to faster simulation by the computer and available inputs, time step in the ABM is shorter. The faster simulation by computer also provided an advantage to the ABM is the longer time horizon than that of the RPG in most of the cases. This advantage allows the model user to analyze the long-term impacts that could not be found during the RPG. However, when it was combined into the hybrid model, the time horizon was only equal to that of the RPG, as in the Mae Salaep and Nam Haen cases.

Farmer is the active agent that existed in all cases. The other agents are diverse and vary by case. A common agent representing the community management is included in four cases, but other agents such as religious leader, national park, government officers and local administrators, foresters, water managers, etc. found in different cases show the diversity of stakeholders concerned and to be involved in the search for resilient water management.

The collective interactions (C) within agent groups in six cases show that a collaborative management of water resources has been stimulated at these sites. Also in six cases (not the same with C), the interactions were through environmental factors (E), for examples, water flow from upstream to downstream villages as in Lingmuteychu, Kengkhar and Maehae cases, or soil erosion at Radi and Mae Salaep sites, or canal water salinity in Bac Lieu. Peer to peer interactions (I), i.e. discussion between two individual agents without participation of the group, were also recorded in four case studies.

Different model components were identified and developed in different cases. These components were based on the nature of conflicts, the related resources and products, and the agents involved and varied in a wide range from physical entities as water and climate, production systems as crop or livestock, to management as irrigation or economic as household finance. Similarly to the agents, these components were not fixed during modeling, but could be modified or added as needed. A relevant example for this dynamics in modeling is the Mae Salaep case with two ComMod cycles (Barnaud et al., 2007). In the first cycle, the researchers' model MAE SALAEP 1 was developed by integration of scientific and indigenous knowledge on farming systems and soil erosion to focus on land use and land degradation. The model was then translated into an initial RPG that could be described as a simplified and non-computerized version so that farmers could validate it. With knowledge on farmers' land-use strategies acquired during the MAE SALAEP 1 gaming sessions, a simpler MAE SALAEP 2.1 ABM with rules and features similar to the RPG was developed. The second cycle was to set up a collective learning process on the socio-economic conditions for adoption of perennial crops by different farm types. A new model version, the MAE SALAEP 2.2, was developed based on the previous version to represent the interactions between investment in perennial crops, formal and informal credit, and off-farm activities; to explore the interactions between decision-making processes at household level and the resultant collective dynamics at community level; and to support the exploration of scenarios with all stakeholders. Similar dynamic processes have been also applied in other case studies.

The number of RPG or ABM or hybrid sessions with the participation of stakeholders also varied by case study. In general, organizing RPG or hybrid sessions took a lot of time and efforts compared to participatory ABM ones. Therefore the maximum number of RPG sessions was only 4 (in Maehae and Bac Lieu), but the maximum of ABM sessions was 8 (at Lingmuteychu site). Besides several sessions with smaller and more homogeneous groups of participants were also organized in Radi, Mae Salaep and Ban Mak Mai cases to increase the involvement of all the concerned players, including the more marginal ones. The agent-based modeling tools used in Lingmuteychu, Mae Salaep and Nam Haen have also been used for training purposes at several Universities in Bhutan, Thailand, France and Japan. Ban Mak Mai case is a special one with many sessions organized for a group of 10-15 participants or small groups of 3-4 participants to emphasize the co-designing and testing characteristics of the ABMs. In this case, the co-designers farmers are already involved in the presentation of "their" ABM to master students at the regional university.

Conclusion

With two objectives, knowledge generation and exchange, and collective decision-making, these eight cases studies showed that the agent-based modeling approach could be applied for diverse conflicting problems in water management under different bio-physical and socio-economic conditions. Although only two key tools, RPG and ABM, were used either separately or integrated into hybrid gaming ABM models, creative thinking and flexibility was required in tailoring them to specific needs and using them in each different cases.

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References

Barnaud, C., P. Promburom, T.R. Gurung, C. Le Page, and G. Trébuil. 2006. Companion Modelling for Collective Learning & Action in Water Management: Lessons learned from three case studies in northern Thailand and Bhutan. Proceedings of the International Symposium "Towards Sustainable Livelihoods and Ecosystems in Mountainous Regions", 7-9 March 2006, Chiang Mai, Thailand. 13p.

Barnaud, C., T. Promburom, G. Trébuil and F. Bousquet, 2007. An evolving simulation/gaming process to facilitate adaptive watershed management in northern mountainous Thailand. Simulation Gaming, 38: 398-420.

Bousquet, F., et al., 2006. Companion modeling for resilient water management: Stakeholders' perceptions of water dynamics and collective learning at the catchment scale. In D. Rocchi: "France and the CGIAR: Delivering scientific results for agriculture development". CGIAR Publication, 2006. 98-101.

Dumrongrojwatthana, P.,C. Barnaud, N. Gajaseni and G. Trébuil, 2007. Companion modeling to facilitate adaptive forest management in Nam Haen sub-watershed, Nan Province, Northern Thailand. In: B. Ekasingh, A. Jintrawet and S. Pratummintra (eds). Proceedings of the 2 nd International Conference on Asian Simulation and Modeling (ASIMMOD), January 9-11, 2007 Chiang Mai, Thailand. 327-333.

Dung, L.C., C. Le Page and C.T. Hoanh, 2007. Participatory simulations of competing aquacultural and agricultural land uses in Bac Lieu province, Mekong Delta, Vietnam. In: B. Ekasingh, A. Jintrawet and S. Pratummintra (eds). Proceedings of the 2nd International Conference on Asian Simulation and Modeling (ASIMMOD), January 9-11, 2007 Chiang Mai, Thailand. 313-318.

Gurung T.R., Bousquet F., and Trébuil G. 2006. Companion modeling, Conflict Resolution and Institution Building: Sharing Irrigation Water in the Lingmuteychu Watershed, Bhutan. In: Ecology & Society 11(2): 36.

Naivinit, W., C. Le Page, M. Thongnoi, G. Trébuil and N. Srisombat, 2007. Using companion modelling to build and validate a multi-agent model on rainfed lowland rice and labour migrations in lower northeast Thailand. Proceedings of the International Conference on Asian Simulation and Modelling 2007 (ASIMMOD2007), 9-11 January 2007, Chiang Mai, Thailand. 306-312.