A computational model based planning approach for integrated resource management with a case study

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Abstract

Regional sustainable development issues, such as sustainable city development and environmental rehabilitation, are complicated management issues. The integrated resource management approach and its related technologies can be applied to these issues. Computational model based planning is required in the institutional design, such as establishment of a tradable water rights system, when an integrated management approach is applied.

Computational model based planning is applied to environmental rehabilitation in Tarim valley for integrated resource management. Tarim valley is situated in the south of Xinjiang Autonomous Region in China. A tradable water rights system could be one of the institutional reform schemes for water resource management. But simulation results show that it is necessary to integrate a tradable grass quota system into the institutional design.

To analyze the economic impact of tradable water rights and a tradable grass quota system, a joint multi-product water rights and grass quota trade model with transaction cost is developed. The model integrates ecological improvement and agricultural activities into a system. The variational inequality approach is applied to transform the game-theory models into computational models. The results of model simulation show that a joint tradable water rights and grass quota system will encourage participates to conserve the water and grass resources at the same time. The study also shows that a computational model based planning approach could provide both qualitative and quantitative results for sustainable region planning.

1 Introduction

Regional sustainable development issues, such as sustainable city development and environmental rehabilitation, are complicated management issues.

According to Jackson and Keys [1] management issues can be depicted in 2 dimensions: complex and divergence. As for the dimension of complexity the problem contexts can be spread along a continuum, ranging from simple to complex. As for the dimension of divergence the issue can be unitary, pluralist or conflictual. Therefore, complicated systems can be complicated unitary systems, or complicated pluralist systems or complicated conflictual systems, or a mix of them.

As the problem becomes more complicated the breakthrough was to abandon the method of trying to include in a model all the myriad of interacting variables that appear on the surface of the problem context. The theoretic research on complexity and chaos after 1960's has contributed to the development of methodology for complicated management systems [2].

Along the dimension of divergence the breakthrough came when the aim of producing one single objective model of a problem situation was abandoned. The trick was to make subjectivity central in the methodological process and to work with a variety of models of the world.

There are 2 groups of works to deal with complicated management issues: the rapid approach, and the game theoretic approach. The rapid approach applied human experience and integrated it into the research. The rapid approach includes "Soft OR" [3], the Wuli-Shili-Renli approach [4], the Rapid Rural Appraisal [5], Participant Observation, and others [6]. Game theory is moving ahead very rapidly now and the breadth and depth of its application to economics, political science, management science and other areas is spectacular. Game theory can provide the basic models for some of the components of systems.

Our experience has indicated that many of the challenged problems we encounter are integrated complicated management issues and we can not divide the issues into some separated issues. Therefore, based on the case of natural resource management, we have built the integrated resource management framework [7], and developed the approach [8] and relevant technologies for complicated management issues [9].

A complicated management issue can be modeled as an integrated management system. An integrated management system is a system comprised of inputs, transformations and outputs. Their inputs can be human resources, natural resources, or man-made resources, or a combination of them. The output can be transformed human resources, transformed natural resources, or man made products, or a combination of them.

The integrated management approach is a system approach to guide the management practices for natural resources, human resources, and man-made resources under the situation of fierce competition and high uncertainty. Integrated management includes vertical integration and horizontal integration.

The relevant technologies for an integrated management approach include flow analysis, characteristics analysis and transformation analysis [9]. The flow analysis includes material flow analysis, energy flow analysis, information flow analysis, and value flow analysis. The characteristics analysis included externality analysis, sustainability analysis, and effectiveness analysis. The transformation analysis includes planning, incentive scheme design and information mechanism design. In this paper we explain these technologies. To overcome the challenge of uncertainty in the analysis a participatory research approach (PRA) is also applied.

2 Background of case study

The Tarim River is 2,179 kilometers long. It is the longest inland river in China. It runs west to east along the northern edge of the Taklimakan Desert, the biggest moving desert in China, and flows into Taitema Lake. The main stream of Tarim is divided into the upper reaches of 495 kilometers, the middle reaches of 398 kilometers, and the lower reaches of 428 kilometers. The glaciers and accumulated snow of the mountains nourishes the Tarim River, which flows through the Basin and nurtures the oases embedded along the edges of the Basin [10].

The Tarim River is mainly fed by six tributaries: the Konqi, Weigan, Kaxgar, Yarkant, Hotan, and Aksu Rivers. Today, the Tarim is mainly replenished by the Aksu and Hotan, and in the flood period, by the Yarkant. The main stream retains a volume of about 398 million cubic meters on average [10].

The river plays an important role in the economic and social development of the Xinjiang Uygur Autonomous Region. It has for a long time been irrigating towns and oasises in the river valley area. There were many famous towns in the valley when the “silk road” passed through.

Tarim valley is a major production base of quality cotton, pears and apricots in China. The total cotton production in this valley is about 10% of the total production in the country. The natural gas well in the valley is the starting point of the West East Natural Pipeline Program in China. The Tarim Valley is home to 7.7 million people. There are 38 counties among 6 regions, with a total area of 920,600 km^2. Household income in the valley is low compared to other areas of China. The net per capita annual income of a rural household is just 1428 RMB Yuan in 1998 [11].

The water resources in the valley are relatively low compared to the China average and the world average, as shown in figure 1.

In recent years, the ecological environment of the Tarim valley has been deteriorating, especially in the lower reaches of the river. Excessive land reclamation, over-grazing and unreasonable use of water in the upper reaches have led to deterioration of the local environment. As a result of irrational exploitation of areas along the river, Taitema Lake dried up in 1972. As the river is on the fringe of the local desert, desertification is also expanding. Ecological degradation is indicated by long-standing droughts, destruction of grasslands and desertification involving severe sand mobilization. The deteriorated eco-system has restricted Xinjiang's social and economic development, and also posed a threat to the environment of other regions of northwest China.

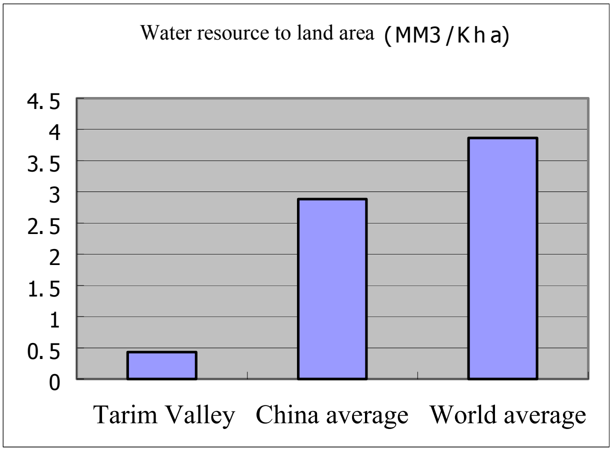

Figure 1: Water resource in Tarim Valley.

To protect the environment and ecology of this valley, more efforts should be made to control the water usage in the upper reaches, to bring under control the middle reaches and to protect the green belt in the lower part.

There are different options to achieve the objective but the costs of them are quite different. International experiences show that an institutional barrier is one of the barriers for water resource conservation [12]. For example, many cases have showed that a tradable water rights system could be one of the cost effectiveness options.

Therefore, the issues in the Tarim valley are integrated issues with ecological degradation, economic underdevelopment and poverty, which are interlinked with each other. A computational model based planning approach which takes into account different natural resources and economic capacity constraints is necessary for policy analysis and institutional design in the valley.

3 An integrated tradable water rights system and grass quota trade model

3.1 Requirement of integrated models

To analyze the economic impact of tradable water rights system a multi-product water rights trade model is developed [13]. It is a game-theoretic model which simulates the market equilibrium of tradable water rights. In the model there are I participates, $i=1,2,3,..,i,...I$. The economic activities are catalogued into D types, $d=1,2,3,..., d,...D$. The decision variable is production output, and production inputs, such as land, labor, water, water rights. Transaction cost is considered in the model. The utility function of the participant is measured by net benefit from the production and the transaction of water rights. The constraints are land constraint, labor constraint, water constraint, and water rights constraint. It is assumed that the product market is an oligarchy monopoly and the market of water rights is complete competition.

The model simulation shows that establishment of a tradable water rights system will encourage participants to conserve water resources but it cannot encourage participants to allocate more water to grass or wood production. On the other hand, to analyze the economic impact of a tradable grass quota system a grass quota trade model is developed [13].

The model simulation shows that establishment of a tradable grass quota system will encourage participants to conserve their grass resources but it did not encourage households to conserve water resources. The results imply that from the perspective of environmental rehabilitation it is necessary to integrate the grass resources into a water resource management planning approach. The discussion on a field visit also showed that it is important to integrate the water rights system with the grass quota system.

3.2 Integrated tradable water rights system and grass quota trade model

An integrated multi-product water rights and grass quota trade model is developed [13].

In the model there are *I* participates. The economic activities are catalogued into *D* types. The decision variable is production output, q_{id}, and production inputs, such as land, labor, water, water rights, grass quota rights. Transaction cost is considered in the model. The objective function and its related constraint are displayed as formula (1) where u_i represents the utility function of participate *I* which is measured by net benefit from the production and the transaction of water rights and grass quota, A_{id}^{m} represents land used for production, L_{id}^{s} represents labour input, $l_{g_i}^{k}$ represents grass quota, w_{id}^{j} represents water consumption, and l_i^j represents water quota. $b_{q_i}^{k}$, o_i^k, $g_{0_i}^{k}$, $b_{g_i}^{k}$, b_{id}^{m}, $b_{L_i}^{s}$, a_{id}, $\varsigma_{g_i}^{k}$, e_{id}, and $\varsigma_{g_i}^{k}$ are parameters.

$$\begin{cases} Max(u_i) \\ st.\sum_{k=1}^{K} b_{q_i}^{k} q_{i1} + \sum_{k=1}^{K} \frac{2l_{g_i}^{k}}{o_i^{k}} + \sum_{k=1}^{K} 2g_0^{k} \le \sum_{m=1}^{M} b_{g_i}^{m} A_{i1}^{m} \\ q_{id} \le \sum_{m=1}^{M} b_{id}^{m} A_{id}^{m}, d \ne 1 \\ q_{id} \le \sum_{s=1}^{S} b_{L_{id}}^{s} L_{id}^{s} \\ q_{id} \le a_{id} \sum_{j=1}^{J} \varsigma_{id}^{j} w_{id}^{j} \\ \sum_{d=1}^{D} h_{id}^{j} w_{id}^{j} \le l_i^j \\ \sum_{d=1}^{D} e_{id} q_{id} \le \sum_{k=1}^{K} \varsigma_{g_i}^{k} l_{g_i}^{k} \end{cases} \quad (1)$$

The net benefit can be calculated with sale income minus production cost including water rights cost, grass quota cost, and transaction cost. When market structure for product q_{id} is oligarchy monopoly sale income of product output depends on market price which is affected by the output of participants.

Assuming the market structure for water rights and grass quota is complete competition, the market clearing formula for water rights and grass quota is described by formula (2):

$$\left[\sum_{i=1}^{I}(l_i^{j0}-l_i^j)\right]\begin{cases}=0, & if\ p^{j*}>0\\ \geq 0, & if\ p^{j*}=0\end{cases} \tag{2}$$

where p^j represents the price for water rights, p_g^j represents the price for grass quota.

4 Simulation of the models and discussion

4.1 Simulation and results

The variational inequality approach can be applied to transform the model into computational models [14]. The modified projection algorithm is applied and it is coded in Matlab.

In the modeling process for the Tarim case participants are the 5 regions: Kezhou, Kashi, Hetian, Akesu, Bazhou. The simulation results show that the cotton production in Kashi and Akesu will decrease by 43% and 19% while the cotton production in Kezhou, Hetian and Bazhou will increase by 160%, 67% and 60% respectively. It also showed that the total cotton production in the valley will decrease by 10%. The simulation shows that mutton production in the valley will increase twofold. This shows that after the establishment of a water rights system and grass quota system participants prefer to plant grass and raise goats rather than cotton production. The simulation shows that the total water consumption for the production activities will decrease by about 40%. This means that sufficient water can be applied for purely ecologically purposes.

4.2 Discussion and recommendation

The results of model simulation show that a joint tradable water rights and grass quota system will encourage participants to conserve the water and grass resources at the same time. Therefore, it is relevant to develop the tradable water rights and grass quota system as an integrated system.

The modeling practice also shows that a computational modeling process could provide both qualitative and quantitative results for sustainable region planning.

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