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Shahbazbegian M.R., Bagheri A.

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Representing systemic strategies to cope with drought impacts using system dynamics modeling. Case study: Hamadan province, Iran

M.R. Shahbazbegian* and A. Bagheri*

*College of Agriculture, Tarbiat Modares University, PO Box 14115-336, Tehran (Iran)

Abstract. Following a drought event, several interactive feedback relations will get involved, whose effects can be realized as drought impacts. That is the behaviour of the components of a socio-economic system in response to the new changes due to drought which will form the system total behaviour in terms of socio-economic-natural responses and/or impacts. Developing relevant strategies to cope with system negative behaviours in a region, the research used a system dynamics approach to provide a unique framework for integrating the fragmented parts of physical and social systems to model the interactive feedback relations in Hamadan province in Iran.

Keywords. Socio-economic drought – System dynamics – Sustainable development – Hamadan – Iran.

La représentation des stratégies systémiques pour faire face aux impacts de la sécheresse en utilisant une modélisation de dynamique des systèmes. Étude de cas : la province de Hamadan en Iran

Résumé. Suite à un épisode de sécheresse, plusieurs relations de rétroaction interactive interviennent, dont les effets peuvent être tenus pour impacts de la sécheresse. C'est le comportement des composantes d'un système socio-économique en réponse aux nouveaux changements dus à la sécheresse qui forment le comportement total du système en termes de réponses socio-économiques adoptées ou naturelles et/ou impacts. Afin d'élaborer des stratégies pertinentes pour faire face aux comportements négatifs du système dans une région, la recherche a utilisé une approche de dynamique des systèmes pour fournir un cadre unique intégrant les parties fragmentées des systèmes physiques et sociaux afin de modéliser les relations de feedback interactif dans la province de Hamadan en Iran.

Mots-clés. Sécheresse socio-économique – Dynamique des systèmes – Développement durable – Hamadan – Iran.

I – Introduction

Drought cannot be only attributed as "natural"; but, it is in fact a "generated scarcity", which is rooted somehow in water management (Taylor *et al.*, 2009). There are several studies using models for policy analysis in order to better understand the influences of alternative policies on drought conditions; but, few has integrated many aspects of the issue. Relying on a system dynamics approach (Sterman, 2000; Hjärth and Bagheri, 2006), the paper argues that there are dynamic mechanisms which originate due to a drought event and then give momentum to other forms of socio-economic impacts. So, the paper starts with an original mechanism responsible for socio-economic consequences in the Hamadan province, Iran. Then, based on the concept of viability loops (Bagheri and Hjärth, 2005, 2007; Bagheri, 2006) and applying a simulation model, it goes further to explore relevant systemic strategies to cope with drought impacts.

II – Conceptual model and systemic strategies

The basic mechanism which initiates drought impacts works in the context of a "Limits to growth" archetype. In this archetype several reinforcing mechanisms are working in the area

which pushes the water consumption to grow. Those mechanisms are: production loop (refers to the attitude of farmers for more cultivation), sectorial expansion loop (refers to the attitude of agricultural sector to expand in terms of more land dedicated to crop area), and regional economic loop (refers to the regional development policies whether they are making the region more dependent on water or other resources).

On the other hand, the reinforcing mechanisms depend on resources particularly on water resources to persist. If the need for water exceeds the yield capacity that the resources can support then the balancing mechanisms will come into effect. If that process is ignored the pressure of water demand will overshoot the regional resources capacity to meet needs, so the system will be faced with water shortages.

It is very important to respect the balancing mechanisms. Thus, viability loops (Bagheri and Hjörth, 2005, 2007; Bagheri, 2006) are suggested to be imposed to help balancing dynamics to work more effectively. Viability loops are balancing mechanisms which are responsible to check reinforcing dynamics and prevent the state of the system not to overshoot its carrying capacity.

To check the system reinforcing mechanisms, at the first step, the production loop is targeted. To use water more wisely it is essential to care about the productivity of ground water resources in Hamadan, therefore, we have to associate a feedback link from resource productivity to the crop pattern in terms of a viability loop. That feedback link, which will serve as a viability loop, is intended to initiate an information flow to support decisions on the agricultural crop patterns in accordance with the productivity of local water resources. As depicted in Fig. 1 an "Agricultural Performance Index: API" is proposed to serve as an index to evaluate productivity of the local water resources in the system. The index is proposed to be calculated as below:

$$\text{Agricultural Performance Index} = \frac{\text{Agricultural Value Added}}{\text{Water Resources Utilization}}$$

The main purpose of that viability loop is to check the "Production Reinforcing Loop" in terms of pushing it towards a utilization pattern with the most efficient resource productivity (Fig. 1).

The second viability loop is intended to control the sectorial expansion loop in accordance with the carrying capacity of water resources in the region. Associating water utilization to the water resources in the region, that viability loop creates an information flow to support decisions on the level of regional agricultural expansion according to the carrying capacity of local water resources (Fig. 1). A "Water Resources Utilization Index (WUI)" is suggested to be calculated as below to serve as a managerial decision factor:

$$\text{Water Resources Utilization Index} = \frac{\text{Water Resources Utilization}}{\text{Local Water Resources Availability}}$$

Finally, the regional economic loop is targeted by the third viability loop to tackle drought socio-economic impacts. The reinforcing loop shows how the agricultural revenues in the region will contribute in the regional economic security. While the process of making revenues in the area is dependent solely on one vulnerable resource, that type of dynamic structure will be expected to impact the economic life of the people. In this case, an econo-diversity policy needs to be initiated to make the region rely on various types of resources to reduce economic vulnerability of the area.

Thus, we propose to impose a diversification strategy in the regional economy to improve the regional robustness. As shown in Fig. 1, a viability loop is proposed to balance the share of agriculture in the regional economic product. An Econo-diversity index (EDI) is also proposed as below to quantify the degree of regional economic diversification and to serve as a supporting tool to make decisions on the level of expansions in each sector.

$$\text{Econo-diversity Index} = \frac{\text{Value Added of each Sector}}{\text{Total Regional Value Added}}$$

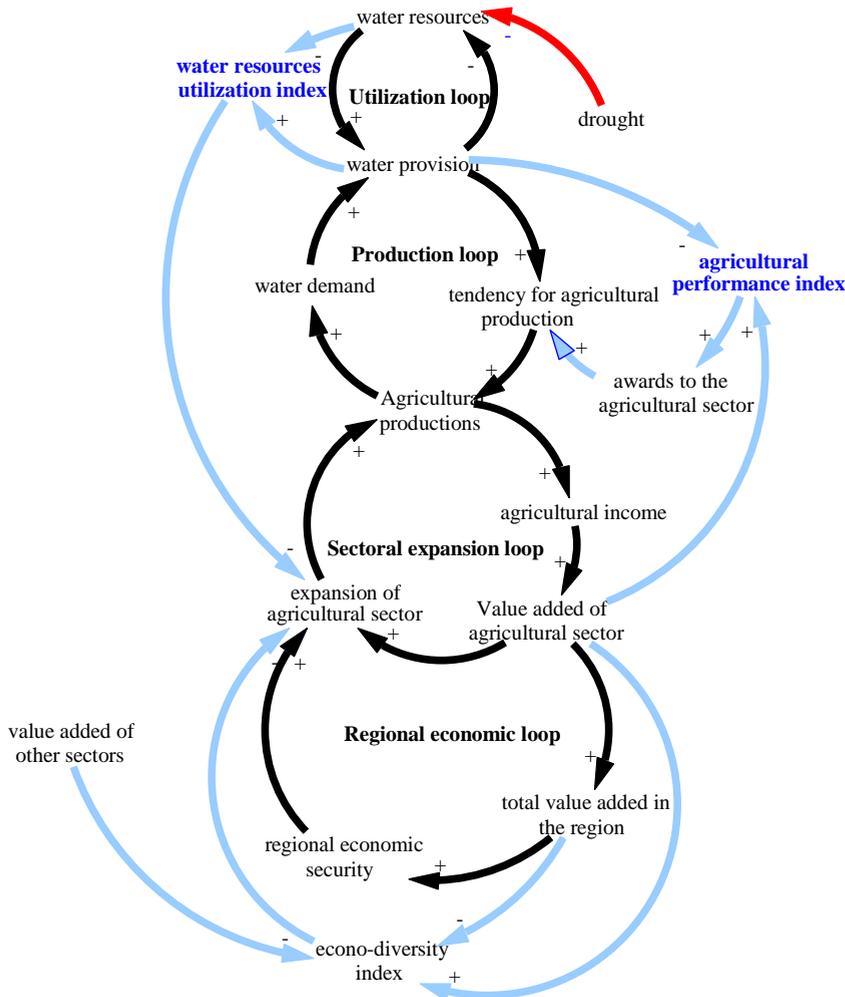


Fig. 1. The basic mechanism (black lines), with viability loops and their indexes (grey lines).

III – Simulation model and policies

A simulation model was built based on the conceptual model in VENSIM. Combinations of climatic and economic situations have been developed as scenarios for the model (Table 1). According to each scenario, different policies have been analyzed. The policies were developed based on the above indexes as below:

- (i) Policy 0 – nothing changed in the model.
- (ii) Policy 1 – considers WUI index to control crop production.
- (iii) Policy 2 – enforces API index to improve water utilization.
- (iv) Policy 3 – applies EDI index to make the economic system less dependent on water.
- (v) Policy 4 – implement Policies 1-3 simultaneously.

Table 1. Scenarios imposed to the model

Scenario	Inputs to the model
1- Human desirable behaviours vs natural bad attitudes	Rainfall halved. Temperature increased by 1.1 folds. Expected value added halved. Groundwater withdrawal halved.
2- Human bad behaviours vs natural desirable attitudes	Rainfall increased to two folds. Temperature decreased by 1.1 folds. Expected value added increased to two folds. Groundwater withdrawal increased to two folds.
3- Human bad behaviours vs natural bad attitudes	Rainfall halved. Temperature increased by 1.1 folds. Expected value added increased to two folds. Groundwater withdrawal increased to two folds.
4- Human desirable behaviours vs natural desirable attitudes	Rainfall increased to two folds. Temperature decreased by 1.1 folds. Expected value added halved. Groundwater withdrawal halved.
5- Business-as-usual (BAU)	Nothing new happens.

IV – Results and discussions

The major consequence of water resources un-sustainable utilization in Hamadan was the fall in groundwater resources levels and in some locales that has led to deep sinkholes. Thus, the suggested policies have been evaluated *versus* their effect on the recovery of groundwater falling levels.

The results for ground water variable have been demonstrated in Fig. 2. It has been shown that policy no. 1 has the most effective influence through the all scenarios. On the other hand, policy no. 2 showed the least effect leading to more rapidly depletion of local ground water resources.

The results show that relying solely on the technology to improve water utilization and ignoring complex interactions leading to more water withdrawal such as crop patterns can be realized as the main cause for initiating drought impacts in the region. According to Fig. 2, applying even all policies in the model can cause only delay in decreasing the ground water level. Actually, none of the policies can fix the decreasing trend in the level of local groundwater resources.

V – Conclusions

There are main differences between drought caused by natural processes and drought caused by human activities or socio-economic drought. So, to cope with each kind of drought events it is needed to find their own specific strategies. The present paper explored strategies to cope with socio-economic drought impacts in Hamadan, Iran, using a system dynamics approach. Particularly, the paper achieved the following outcomes:

(i) A conceptual dynamic model was proposed to explain mechanisms responsible to initiate drought impacts. In the conceptual model it was shown that the growing processes in other sectors which make the components of water consumption should be brought under control in accordance with the resources capability to provide water.

(ii) Copping strategies associated to mechanisms causing drought impacts were suggested relying on the concept of viability loops.

(iii) A simulation model in VENSIM was built to analyze the effects of strategies in the case of Hamadan.

(iv) The suitable strategy was proposed to make the socio-economic system of Hamadan capable enough to survive in drought shocks with leaving the least impacts on the local groundwater resources.

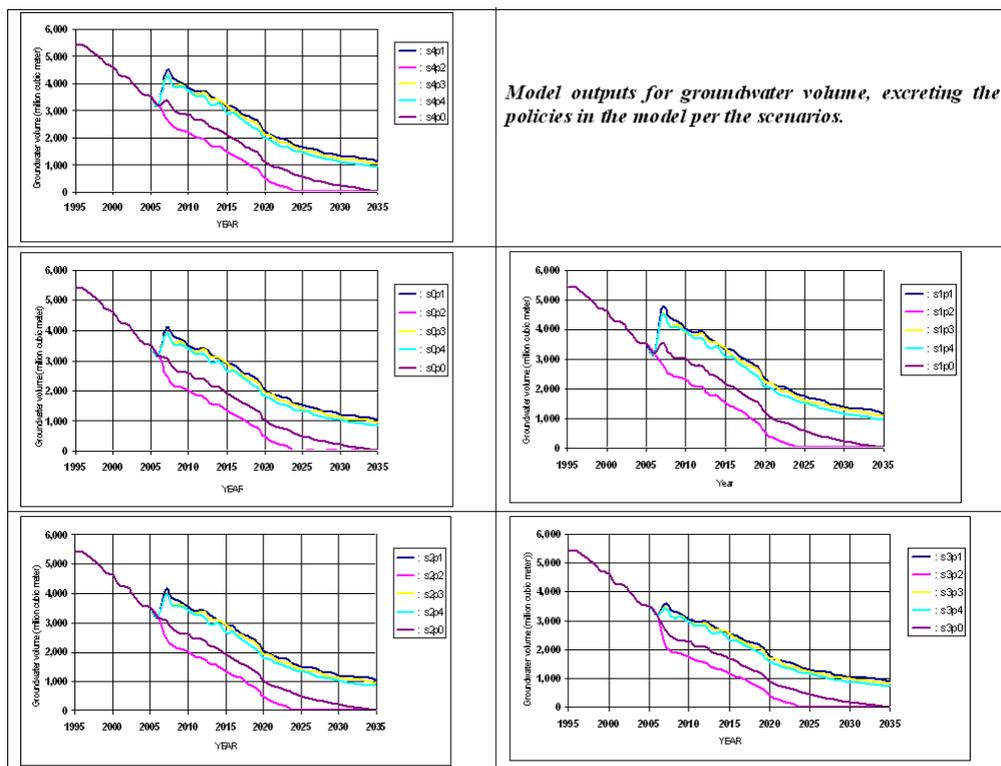


Fig. 2. Results for the groundwater variable.

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