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A Novel Water Resource Allocation Model Comparing with the Conflict Resolution Method

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Abstract. In this study, a novel mathematical model applied to resolve the conflicts between stakeholders in water resource allocation for the agricultural sector. In addition, the developed model based on prey-predator equation could calculate pay-offs of stakeholders due to agricultural water consumption in the time series. However, according to competition nature of the prey-predator equation, the water division between up and downstream in the water basin simulate. And, the main advantage of this approach is producing equitable water sharing between stakeholders to ensure sustainable development in the region. Finally, a comparison between the result of the new model and prevalent optimization method, Nash bargaining solution for the Atrak water basin suggests the merit of the proposed model.

Keywords: water sharing, prey-predator equation, conflict resolution

1. Introduction

Water allocation is old issue in management of water resources that caused serious problems because of the conflicts between stakeholders. The need to prove right water allocation methods and associated management institutions and policies has been recognized by researchers, water planners and governments. Many studies have been carried out in this domain, but there are still many obstacles to reaching equitable, efficient and sustainable water allocations [1].

Conflict is a natural disagreement resulting from individuals or groups differing in attitudes, beliefs, values, or needs. Conflicts in water management often involve interactions between various factors, water subsectors, and stakeholders in the water resources management process [2]. Water resources management involves many uncertainties associated with the physical processes, available data, and level of our knowledge. Its availability in a particular locality and point of time usually cannot be predicted in advance accurately.

Therefore, uncertainty as well as scarcity is typically the reason conflicting scenarios arise among stakeholders, in sharing water and protecting their interests. When a river basin traverses across multiple legal, political, and international boundaries, the number of potential stakeholders and their specific interests increases, making the conflict resolution process increasingly complicated [3].

Conflict between international basins that include political boundaries of two or more countries is a common problem. This covers more than half of Earth's land surface, host about more than 40 per cent of the world's population, and account for about 60 percent of global river flow [4]. Water resources systems are complex to model at a global level because of dissimilar real-world systems [5]. For example, the Mekong River flows through South-east Asia to the South China Sea through Tibet, Myanmar (Burma), Vietnam,

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Laos, Thailand and Cambodia. Its ‘development’ has been restricted over the past several decades because of regional conflicts. There are many literatures that apply traditional methods such as linear programming [6], [7] and conflict resolution methods applied for water-related problems [8], [9].

In this research, to consider the competition nature of conflict resolution in water resources allocation, for the first time, the prey-predator equation is considered. Whereas the prey-predator model is the simplest model in the ecology showing how populations can cycle. And it was one of the first strategic models to explain qualitative observations in natural systems [10]. In fact, it was initially proposed by A. J. Lotka “in the theory of autocatalytic chemical reactions” in 1910 and extended to modelling interaction between prey and predators. Likewise, another scientist, V. Volterra, made a statistical analysis of fish catches in the Adriatic Sea independently investigated the equations in 1926. As it can be seen, the Lotka - Volterra equations have a long history of use in economic theory; and their initial application was credited by economic scientists many years ago [11].

2. The Proposed Model

Water management problems usually face conflicts among the stakeholders because of limited resources and different preferences. These problems become more complicated when stakeholders have conflicting criteria [12]. In such cases, there are mathematical solutions such as Nash bargaining solution, Kalai-Smorodinsky Solution, Equal Loss Solution, Area monotonic solution to optimize water allocations between stakeholders. In this paper the proposed method compared with Nash solution that is the general optimization model.

In this research, prey-predator equation is considered as a competition model for conflict resolution in water resource allocation. The prey-predator, also known as the Lotka–Volterra equation set, is a pair of first-order, non-linear, differential equations. These equations often used to describe the dynamics of biological systems in which two species, prey and predator, interact. And they change in time according to the pair of Equations 1 and 2.

$$\frac{dx}{dt} = x(\alpha - \beta y) \tag{1}$$

$$\frac{dy}{dt} = -y(\gamma - \delta x) \tag{2}$$

Where, x and y are the number of prey (for example, rabbits) and some predator (for example, foxes) respectively. In addition, the growths of the two populations against time define by dy/dt and dx/dt and the time factor is entered by t. Besides, a set of fixed constants α (the growth rate of prey), β (the rate at which predators destroy prey), γ (the death rate of predators), and δ (the rate at which predators increase by consuming prey) are defined. In the Lotka-Volterra model, a number of assumptions regarding the environment and growth of the prey and predator populations are considered: (i) The prey population finds plenty food always, (ii) The food supply of the predator population depends only on the prey populations, (iii) The rate of change of population is proportional to its size, (iv) During the process, the environment does not change for one species, and the genetic adaptation is enough slow.

In water resource allocation, the parameters of prey-predator equation could be assigned in various forms. For instance, the amount of the water supply in upstream and downstream, in one basin is considered as the prey and predator populations respectively. In this study, the net benefit of agricultural water consumption for each stakeholder should be spotted populations of prey and predator. To set assignment Lotka-Volterra model to water resource allocation, Equations 3 and 4, illustrate prey and predator equations.

$$\frac{dNB_U}{dt} = \alpha NB_U - \beta NB_U .NB_D \tag{3}$$

$$\frac{dNB_D}{dt} = -\gamma NB_D + \delta NB_D .NB_U \tag{4}$$

where NB_U is Net Benefit of upstream province due to amount of agricultural water supply similar to NB_D downstream province one. Besides, using historical data and forecasting future condition in the upstream and downstream provinces; it is comprehensible that the time-dependent factors α, β, γ, and δ can be determined.

3. Case Study

Atrak water basin located on the eastern north of Iran has 26430 km2 areas and also shared between two provinces upstream to downstream called Khorasan (Kh) and Golestan (G), respectively (Figure 1). Although the domestic and industrial water requirements are delivered adequately in region, there is a considerable shortage in agricultural water supply. Lack of regulated water allocation between stakeholders in two provinces, there is a tense water crisis in downstream due to exceed water utilization for irrigation in upstream.

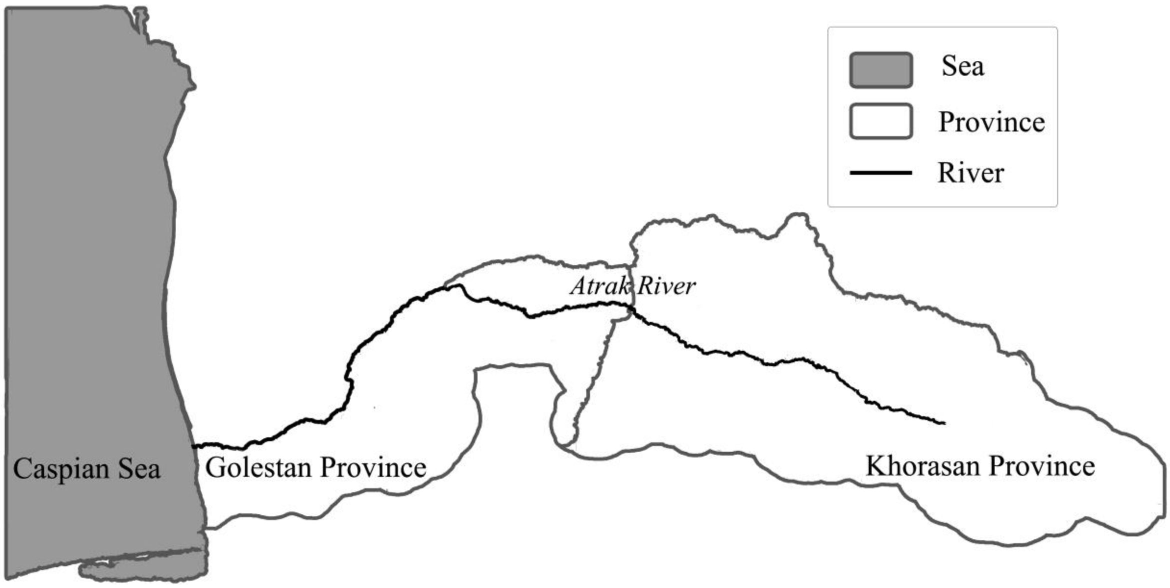

Fig. 1: General location of *Atrak* basin.

According to water consumption for crop production, the net benefit of the upstream region (Khorasan province) estimated from AW_{Kh} the amount of available water for irrigation in the status quo situation in Equation 5. The net benefit will be varied by time because of different crop pattern and instability in the water trade and also economical inflation. So the net benefit of Khorasan province will be estimated in the specific time horizon (in this study 50 years) by Equation 6.

$$NB_{Khi} = -0.04AW_{Kh}^{2} + 1.01AW_{Kh} \tag{5}$$

$$NB_{Kht} = -0.04AW_{Kh}^{2.17} + 1.51AW_{Kh} \tag{6}$$

Similarly, the net benefit of Golestan province in current situation is calculated by Equation 7. And it can be estimated by Equation 8 for the development time horizon.

$$NB_{Gi} = -0.05AW_{G}^{2.24} + 1.85AW_{G} \tag{7}$$

$$NB_{Gt} = -0.05AW_{G}^{2.17} + 1.5AW_{G} \tag{8}$$

4. Result and Discussion

The prey-predator model of the Atrak basin is developed by VENSIM software and resulted in Figure 2, shows the time-series solution of the net benefits for up and downstream provinces. When the prey population is increasing, the predators have a high food source; so their numbers start to increase, thereby eventually driving down the prey population. Afterwards, when the prey population gets low, the number of predators will be decreased because of the insufficient food; this cycle repeat more and more.

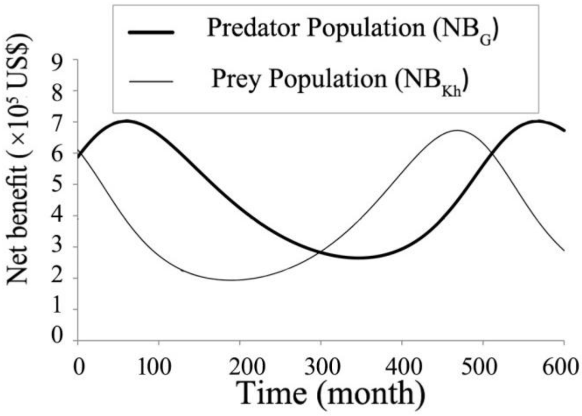

Fig. 2: The time series solution of prey-predator Equation.

This model produces a nonzero equilibrium that is neutrally stable. This point means that both pray, and predator has stable situation. In this case, the stable point for Atrak basin is (4.4, 3.8) that stand for the net benefit for Khorasan and Golestan provinces, respectively. To compare the results of the proposed method by common approaches in conflict resolution, Nash solution was applied in Atrak basin for water allocation between two provinces. The computational results of Nash bargaining are demonstrated in Table 1. In this table "P" parameter represented the power of Khorasan province that brings changeable weights in objective function for this player, and the "OF" parameter shows the objective function of the Nash's method that mentioned before. And also "It" term is defined as the iteration of solver to calculate the object function for each power.

Table 1: The computational results of *Nash* solution with changeable weights.

Solution	P	NB_{Kh}	AW_{Kh}	NB_G	AW_G	F_{Kh}	F_G	OF	It
Non-Symmetric	0.1	3.890	2.820	7.048	5.832	0.424	0.9225	0.853	4007
	0.2	4.596	3.427	6.849	5.618	0.501	0.896	0.798	3306
	0.3	5.142	3.919	6.598	5.354	0.560	0.863	0.758	2018
	0.4	5.635	4.387	6.282	5.032	0.614	0.822	0.731	1896
	0.5	6.113	4.870	5.876	4.632	0.666	0.769	0.716	2075
	0.6	6.600	5.400	5.346	4.133	0.719	0.699	0.711	2452
	0.7	7.120	6.016	4.637	3.499	0.775	0.607	0.721	842
	0.8	7.697	6.787	3.654	2.674	0.838	0.478	0.749	1166
	0.9	8.364	7.868	2.224	1.564	0.911	0.291	0.813	1416
Symmetric	_	6.112	4.870	5.875	4.632	0.665	0.769	0.512	1403

In addition, to compare the proposed method with Nash solution, results of prey-predator model belongs to Khorasan province as a prey is revealed in Figures 3-a. Consequently, the hatched area is the Nash boundary result for this province between weights P=0.1 for lower limit to P=0.9 as upper bound. Although Nash solution is calculating by optimizing approach, but the fact is it brings the static point finally and couldn't simulate the real operation in a basin. So it is doubt yet to accept the results for safe water allocation in the future. Truly, the prey-predator model can simulate the action of prey in times, and it seems this closer to real operation during the simulation time period. By the way, as seen in Figure 3-a, the prey population descends to lower limit of Nash's boundary. Similarity, to compare proposed method with Nash solution, the results of prey-predator model belongs to Golestan province as a predator in downstream is shown in Figure 3-b. As shown in this Figure, the boundary of Nash solution coverage the variation of proposed method results completely. The above comparing could prove that two methods have close result, but the action of them is different in some aspects.

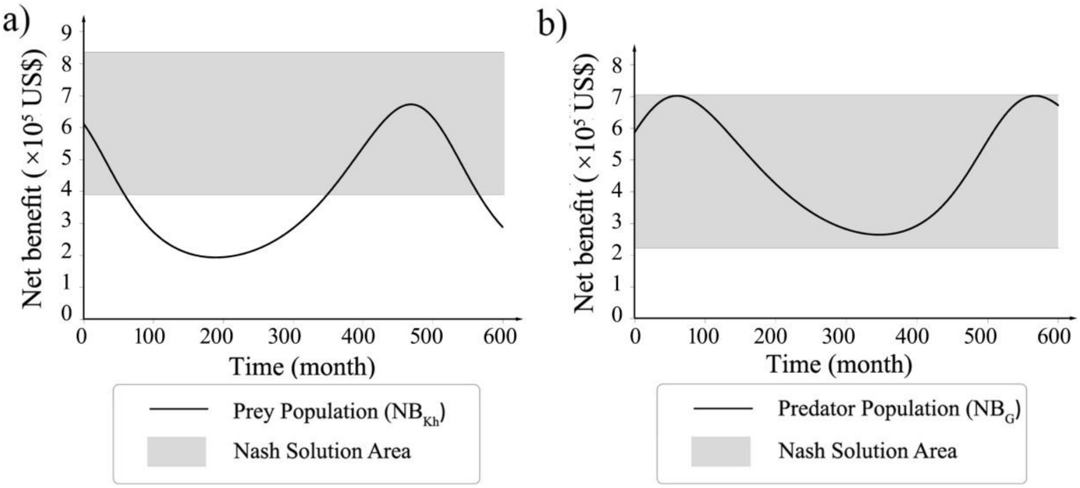

Fig. 3: Comparison results between proposed model and Nash solution, a) Khorasan province and b) Golestan province.

5. Conclusion

Prey-predator model was applied for water allocation between two stakeholders in water basin scale. And this approach is introduced as a conflict resolution method innovatory. Some advantages such as dynamic solution and stability in time made it considerable. In addition, it was compared with common conflict resolution method, Nash bargaining solution that calculated with the LINGO software as an optimization model. Clearly, the results show Nash bargaining method produced static and unique solution, but there is not any guaranty for stability water allocation in the water basin in time. While, by the application of the prey-predator equations, one could assure the sustainability of the water allocation in a specific time period. Moreover, traditional methods produced static and firm solution forever unlike the Lotka - Volterra model. The main advantage of the proposed model is estimating water allocation in every time step for each stakeholder, dynamically.

6. References

[1] Wang, L. (2005). "Cooperative water resources allocation among competing users," University of Waterloo.

[2] Nandalal, K., Simonovic, S. P., and Programme, I. H. (2003). State-of-the-art Report on Systems Analysis Methods for Resolution of Conflicts in Water Resources Management: A Report Prepared for Division of Water Sciences UNESCO, UNESCO.

[3] Wolf, A. T. (1998). "Conflict and cooperation along international waterways." Water policy, 1(2), 251-265.

[4] Wolf, A. T., Kramer, A., Carius, A., and Dabelko, G. D. (2005). "Managing water conflict and cooperation." State of the World 2005: Redefining Global Security, 80-95.

[5] Davies, E. G. R., and Simonovic, S. P. (2011). "Global water resources modeling with an integrated model of the social–economic–environmental system." Advances in Water Resources, 34(6), 684-700.

[6] Devi, S., Srivastava, D., and Mohan, C. (2005). "Optimal water allocation for the transboundary Subernarekha River, India." Journal of water resources planning and management, 131(4), 253-269.

[7] Grabow, G. L., and McCornick, P. G. (2007). "Planning for water allocation and water quality using a spreadsheet-based model." Journal of water resources planning and management, 133(6), 560-564.

[8] Kucukmehmetoglu, M., and Guldmann, J. M. (2004). "International water resources allocation and conflicts: the case of the Euphrates and Tigris." Environment and Planning A, 36(5), 783-801.

[9] Madani, K., Rheinheimer, D., Elimam, L., and Connell-Buck, C. (2008). "A Game Theory Approach to Understanding the Nile River Basin Conflict."

[10] Lotka, A. J. (1925). Elements of physical biology, Williams & Wilkins company.

[11] Goodwin, R. M. (1967). "A growth cycle." Socialism, capitalism and economic growth, 54-58.

[12] Zarghami, M., and Szidarovszky, F. (2011). Multicriteria Analysis: Applications to Water and Environment Management, Springer Verlag.