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A framework model for water-sharing among co-basin states of a river basin

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ABSTRACT

A new framework model is presented in this study for sharing of water in a river basin using certain governing variables, in an effort to enhance the objectivity for a reasonable and equitable allocation of water among co-basin states. The governing variables were normalised to reduce the governing variables of different co-basin states of a river basin on same scale. In the absence of objective methods for evaluating the weights to be assigned to co-basin states for water allocation, a framework was conceptualised and formulated to determine the normalised weighting factors of different co-basin states as a function of the governing variables. The water allocation to any co-basin state had been assumed to be proportional to its struggle for equity, which in turn was assumed to be a function of the normalised discontent, satisfaction, and weighting factors of each co-basin state. System dynamics was used effectively to represent and solve the proposed model formulation. The proposed model was successfully applied to the Vamsadhara river basin located in the South–Eastern part of India, and a sensitivity analysis of the proposed model parameters was carried out to prove its robustness in terms of the proposed model convergence and validity over the broad spectrum values of the proposed model parameters. The solution converged quickly to a final allocation of 1444 million cubic metre (MCM) in the case of the Odisha co-basin state, and to 1067 MCM for the Andhra Pradesh co-basin state. The sensitivity analysis showed that the proposed model's allocation varied from 1584 MCM to 1336 MCM for Odisha state and from 927 to 1175 MCM for Andhra, depending upon the importance weights given to the governing variables for the calculation of the weighting factors. Thus, the proposed model was found to be very flexible to explore various policy options to arrive at a decision in a water sharing problem. It can therefore be effectively applied to any trans-boundary problem where there is conflict about water-sharing among co-basin states.

1. Introduction

Water is essential to sustain life, and its scarcity can be directly linked to conflicts among co-basin states/nations (Garg and Hassan, 2007; Menzel and Matovelle, 2010). History is replete with examples of violent conflicts over water (Butts, 1997). Most of the time, the quantity of water to be shared among co-basin states constitutes the main issue pertaining to water-related conflicts. For example, in the Cauvery basin of India, a water-sharing conflict emerged between the downstream co-basin state, Tamilnadu and the upstream co-basin state, Karnataka. The issue referred to decreases in the water volume for irrigation by Karnataka owing to the increase in the supply of irrigation water for agriculture, and as such, affected the share of the downstream release of water to Tamilnadu for irrigation. Both of the co-basin states did not accept the adjudication of the tribunal (Iyer, 2002) constituted to settle the dispute, resulting in violence along the Cauvery river and leading to social and political unrest. The reason for not accepting the tribunal/court award was that these verdicts appeared to be based on subjective decision-making strategies and lacked an objective and scientific analysis of the water-sharing problem. Traditional approaches for conflict resolution normally rely on classical game theory (Parrachino et al., 2006; Madani, 2010) and/or outside mediation. Wolf (1998) observed that traditional conflict resolution approaches provide solutions wherein one party gains at the expense of the other even when the systems involve only a few stakeholders. Simonovic and Bender (1996) proposed a dynamic model to address conflicts through collaborative processes with the involvement of the

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stakeholders. Cobble and Huffman (1999) also explored system dynamics approaches to conflict resolution. Wolf (2000) presented a system-dynamics-based indigenous approach to water conflict negotiations among nations. Simonovic (2002a,b) developed a world water model and presented a strong feedback relation between the availability of water and the different development sectors throughout the world. Nandalal and Simonovic (2003) presented a system-dynamics-based conflict resolution model to resolve the conflict between two stakeholders in a hypothetical water resource system that extends across the boundaries of two different administrative units. In addition to the assumption of arbitrary weighting factors, the referred model dealt with the absolute values of the model variables and was likely to distort the results whenever there were significant differences in the absolute value of variables for different stakeholders.

Even though numerous attempts have been made by researchers across disciplines (Wolf, 2002; Dinar et al., 2007) to ameliorate the conflicts, these were met with limited success in view of the limitations in adopting the variables in an objective manner, and the inability to formulate rational approaches for the assignment of the weights to the co-basin states for water-sharing. The general principle for trans-boundary water-sharing (Joseph, 2007) among co-basin states calls for a 'reasonable and equitable' share of water (ILA, 2004. However, there is no definite approach for allocating water among co-basin states. Even the Berlin rules on water resources (ILA, 2004,) summarise the factors/variables to be considered while making decisions on water allocation, but they do not provide any objective criteria or formulations on how to use these factors for water allocation. There is a lack of developed theoretical frameworks for water allocation among co-basin states, and the question still remains on how to translate these variables into objective models to determine the reasonable and equitable distribution of water among co-basin states. In this context, a new model is proposed in the present study for water-sharing among co-basin states by conceptualising and formulating the struggle of the co-basin states in terms of the governing variables, leading to the reasonable and equitable allocation of the water of a river basin in an objective manner. The present study also proposed a new conceptualisation and formulation for assessment of the weighting factors of the co-basin states for water-sharing by taking into account the governing variables.

2. Water-sharing model

The allocation of the limited amount of water available in the basin to the co-basin states has led to conflicts among co-basin states because the views of each state about their entitlement differ based on their present and perceived future demands. As such, an allocated amount of water that falls short of their aspired target triggers conflicts among them. Correspondingly, the co-basin states start fighting among themselves in their effort to gain their target water allocations. Such struggle continues till an equilibrium point is reached and can be conceptually represented in a simplified form as shown in Fig. 1 for the case of two co-basin states 'X' and 'Y'. In general, a detailed conceptualisation and formulation is needed for the reasonable and equitable allocation of the water of a river basin in an objective manner and this constitutes the focus of the present study.

2.1. Conceptualisation and model formulation

The allocation of water to any co-basin state is governed by many influencing variables. In the present model, the share of water for any co-basin state has been assumed to be primarily a function of the following major variables that need to be considered. However, the authors have proposed a general formulation, and therefore any number of variables can be considered, if required.

- Drinking water demand of each co-basin state.
- Agricultural demand of each co-basin state.
- Industrial demand of each co-basin state.
- Any other significant demand.
- The geographical basin distribution in the territory of each co-basin state (i.e. co-basin state catchment area).
- Arable area in each of the co-basin states.
- Rainfall distribution over the catchment area of each of the co-basin states, and hence the contribution to the total volume of water by each co-basin state.
- Existing utilisation of water by the co-basin states.

The deviation in the 'allocation' of water to any co-basin state other than its 'target' causes 'discontent'. The discontent of a co-basin state was considered as the difference between the aspired target of a co-basin state and the water allocated to that co-basin state. Therefore, it was considered conceptually essential to normalise the discontent and all the other variables before they can be used in a water-sharing problem since their absolute values can lead to distortions in the results, particularly when the values of the variables vary significantly among co-basin states. Hence, all the variables have been normalised in the proposed model. Let there be 'n' co-basin states, which compete for their targeted share of water from the available water of a basin. The 'normalised discontent' of the i^{th} co-basin state (DCT(i)) is defined as the difference between the target (TGT(i)) and the allocation (ALC(i)) divided by its target when the target exceeds the allocation (ALC (i)). The value of this variable is zero when the target is less than the allocation. The discontent of the i^{th} co-basin state can be expressed in accordance to Eq. (1).

$$\mathrm{DCT(i)} = \begin{cases} \frac{\mathrm{TGT(i)-ALC(i)}}{\mathrm{TGT(i)}} & \text{if } \mathrm{ALC(i)} < \mathrm{TGT(i)} \\ 0 & \text{if } \mathrm{ALC(i)} \geqslant \mathrm{TGT(i)} \end{cases} \tag{1}$$

Where, i is the index of co-basin states, TGT(i) is the targeted amount of water of the i^{th} co-basin states, ALC(i) is the allocation of water to the i^{th} co-basin state, and DCT(i) is the normalised discontent of the i^{th} co-basin state.

Let us also define the level of 'satisfaction' (STF(i)) of the i^{th} co-basin state in a normalised form as the ratio of 'allocation' to 'target'. The satisfaction for the i^{th} co-basin state can then be written in a general form in accordance to Eq. (2).

$$\mathrm{STF(i)} = \begin{cases} \frac{\mathrm{ALC(i)}}{\mathrm{TGT(i)}} & \text{if } \mathrm{ALC(i)} < \mathrm{TGT(i)} \\ 1 & \text{if } \mathrm{ALC(i)} \geqslant \mathrm{TGT(i)} \end{cases} \tag{2}$$

where, STF(i) is the normalised satisfaction level of the i^{th} co-basin state.

In the present study, the variables 'normalised discontent' and 'normalised satisfaction' have been interchangeably referred to as 'discontent' and 'satisfaction', respectively.

The target of the i^{th} co-basin state (TGT(i)) represents the summation of all the types of demand for the water for the i^{th} co-basin state. Accordingly, the expression for the 'Target' of the i^{th} state can be expressed in accordance to Eq. (3).

$$\mathrm{TGT(i)} = \sum_{j=1}^{p} \mathrm{DSV(i,j)} \tag{3}$$

where, p is the number of the demand-side variables, and DSV(i, j) denotes the j^{th} demand variable for the i^{th} co-basin state. In addition to this, different co-basin states are associated with different weighting factors (w(i)) to have their claims for more water from