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Scenario planning for water resource management in semi arid zone

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ABSTRACT

Scenario planning for water resource management in semi arid zone is performed using systems Input-Output approach of time domain analysis. This approach derived the future weights of input variables of the hydrological system from their precedent weights. Input variables considered here are precipitation, evaporation, population and crop irrigation. Ingles & De Souza's method and Thornthwaite model have been used to estimate runoff and evaporation respectively. Difference between precipitation inflow and the sum of runoff and evaporation has been approximated as groundwater recharge. Population and crop irrigation derived the total water demand. Compensation of total water demand by groundwater recharge has been analyzed. Further compensation has been evaluated by proposing efficient methods of water conservation. The best measure to be adopted for water conservation is suggested based on the cost benefit analysis. A case study for nine villages in Chirawa region of district Jhunjhunu, Rajasthan (India) validates the model.

1. Introduction

A challenging role has been played by scenario development in identifying the possible circumstances and their impact in future instances (Schoemaker, 1995). Although future cannot be predicted, yet it is required to manage its potential requirements and their fulfillment. This generates the need for scenario development. Scenarios force organizational planners to consider paradigms that challenge their current thinking focusing on the long term and short term stories about the future (Chermack et al., 2001). It helps to estimate outcomes of any system for various circumstances. A variety of methodologies and models have been developed for diverse areas of research incorporating their relevant parameters or factors.

Over-exploitation of water resources compared to their replenishment draws attention towards water management for future generations. Rapid economic development coupled with other human activities cause this transition of water resources (Kulshreshtha, 1998). Therefore, water resource planning can be described as a guiding resource for water management to achieve special goals (Huaicheng and Beanlands, 1994). Sustainable water resource management requires ideally accurate estimations on per capita consumption and a good understanding of the factors influencing the consumption (Wa'el et al., 2016). Insufficient water resources with respect to demands from different agents may cause water conflicts (Oftadeh et al., 2016). Balancing human demands for water with environmental requirements to maintain functioning ecosystems requires the quantification of ecological water requirements (Yuan et al., 2016). A watershed, a groundwater or a river basin can be focused for scenario planning and management (Barrow, 1998). Water resource planners have learned to plan, design, build and operate structures that increase the benefits people can obtain from the water resources (Cooper and Bottcher, 1993).

Scenario planning is primarily based on a prediction process to generate the possible outcomes in future. More the volume of historical data better will be the prediction range. Lesser data may cause wide divergence which may fall under unexpected/extreme conditions. Various prediction techniques have been used with respect to one or more factors affecting a hydrological system. An ANN (Artificial Neural Network) approach has been used to project future salinity concentration, since lesser precipitation and decreased stream flows cause higher salinity concentration in rivers (Suen and Lai, 2013). Similarly, river flows are forecasted using ANN on an hourly basis resolving accurate estimation of extreme flows (Kourgialas et al., 2015). Uncertainties presented in terms of fuzziness and randomness have been incorporated into a multilayered scenario tree using Multistage Fuzzy-Stochastic Quadratic Programming (MFSQP) approach for agricultural water management (Li et al., 2009). A generalized fuzzy two-stage stochastic programming (GFTSP) method has been developed for planning water resources management systems under uncertainty (Fan et al., 2015). A fuzzy-Markov-chain based stochastic dynamic programming (FM_SDP) method has been developed for tackling uncertainties expressed as fuzzy sets and distributions with fuzzy probabilities (DFPs) in reservoir operation (Fu et al., 2012). IMSIP (Inexact Multistage Stochastic Integer Programming) facilitated analyses of the multiple policy scenarios that

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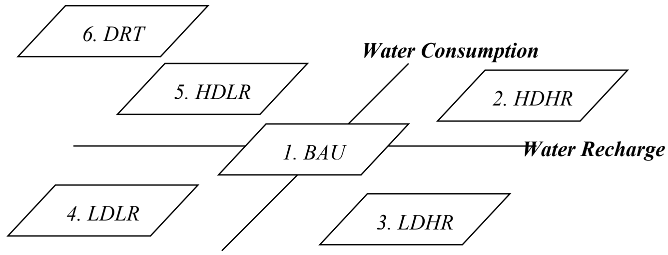

Fig. 1. Global business matrix of scenarios selected.

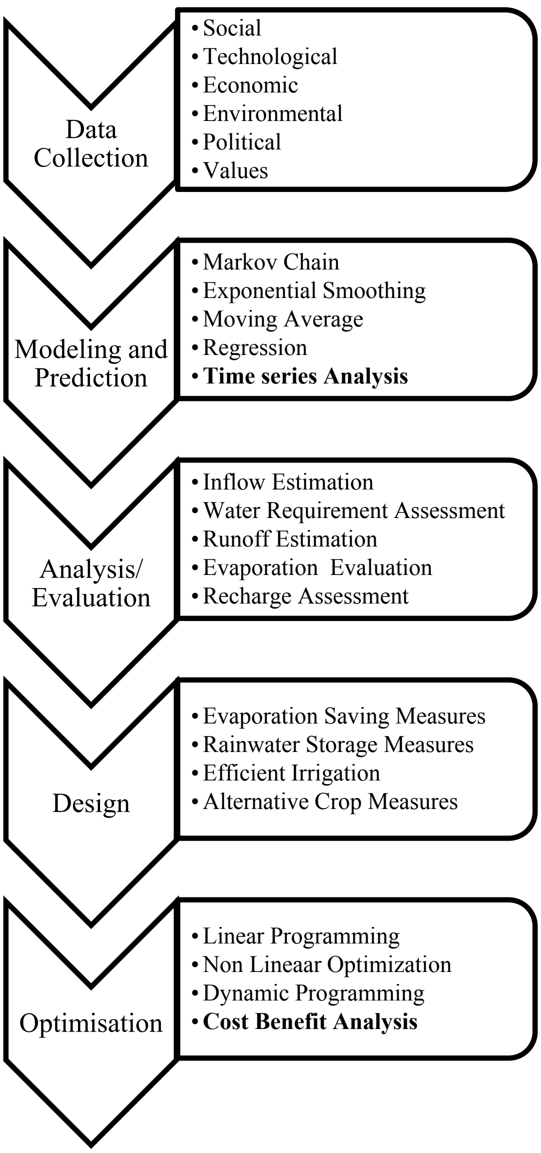

Fig. 2. Methodology flowchart.

are associated with economic penalties when the promised targets are violated (Li et al., 2008). A simulation model for change in land use patterns under drought scenarios has been developed combining top down system dynamics model, bottom up cellular automaton model and the artificial neural network model (Wang et al., 2011). Integration of supply, demand, and asset management processes in system dynamics model simulated the proposed changes to water governance (Sahin et al., 2016).

The encountered methods like System Dynamics, Markov Model, ANN, Fuzzy logic and stochastic programming are found complex and have a rigorous process of prediction. To apply such methods of prediction, one must be comfortable with soft computing and statistics. Here the idea is to generalize such methods so one can apply them with lesser and general information; e.g. using historical data and time step to forecast. Keeping this in mind a generalized method of prediction has been developed using Systems Input-Output approach from a traditional moving average method of forecasting. The method has been applied over a region of 109 square kilometers area comprising nine villages in Chirawa block of district Jhunjhunu, Rajasthan (India). Different sets of parameters like precipitation, population, evaporation, and irrigation are considered for scenario planning.

1.1. Water management

Water is one of the most important natural resources. Its preservation is necessary for the future generations for a sustainable life on the Earth. Underground aquifers (groundwater), meteorological rainfall (precipitation) and river flows (surface water) provide water for various purposes of mankind. Their potentials have got declined due to excessive usage, limited replenishment, climate change, increasing demands and changing land use scenarios (Kløve et al., 2014). The pavement of the land by urban infrastructures generates more rainfall runoff instead of percolation inside the soil. Urban planning and development are suggested based upon the microclimatic conditions to plan the further development (Wong et al., 2011). The rise in temperature is leading the rise in evaporation. This may evolve the condition of drought due to multiple climatological and hydrological parameters (Mishra and Singh, 2010; Vicente-Serrano et al., 2012). Parameters triggering the extinction of water resources should be identified to measure their effects in coming future.

1.2. Factors

All the variables for any type of scenario building fall under a term referred to as STEEPV (Social, Technological, Economic (macro), Environment, Political, and Values) (Tankersley, 2006). These factors include socioeconomic, anthropogenic and climatic variables (Wang et al., 2011; Mao et al., 2014). All these factors are categorized as predictable, unpredictable, important and unimportant. The factors which are unimportant and predictable are excluded from the scenario planning. Important and unpredictable factors are always considered. All the variables considered will inhibit the property of evolution and definitely evolve after a time period. Simulating the evolution pattern of these variables helps to analyze their effects on the water resources in future. Here we have used the systems input-output approach for modeling the future states of such factors. The model has been developed using the recurrence relation identified from moving average method of extrapolation described in the next section.

1.3. Moving average method

Moving average method of forecasting is one of the time series techniques which use only recent history and represents multiple observations. It places more weight on the most recent observation (Gupta, 2005). The steps performed in the method are shown from Equation (1) to Equation (3).

1. Calculate Simple Moving Average (SMA) with N = 2, 3, 4, 5, …, n

$$M(t) = \frac{X(t) + X(t-1) + \ldots + X(t-n+1)}{n} \tag{1}$$