Combining system dynamics modeling with Bayesian Network (SDM-BN) for assessing water scarcity in Iran

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Introduction

- Water scarcity for domestic, agricultural, and industrial sectors is considered one of the most important risks for society (Howell 2013). It occurs when the water demand is high compared to the physical water availability.
- Climate change influences water availability but also water demand and in many regions exacerbates water scarcity conditions (IPCC, 2014). Assessing climate change risks is a serious challenge for water managers due to the inherent high complexity and the high degree of uncertainty (Döll and Romero-Lankao, 2017; Gallina et al., 2016).
- To acknowledge and manage these inherent uncertainties, a risk-based approach should be integrated with water management (Döll et al., 2015). Effective assessment of water scarcity risks should be based on sufficient knowledge of risk parameters, inter-relations between risk components and the dynamic and multi-dimensional nature of the risk.
- This comprehensive view enables decision-makers and experts to develop climate change adaptation plans with a high level of confidence, taking into account risk aversion (Gain and Giupponi., 2015).

Research innovation

Provide comprehensive framework that capture:

- The dynamic trend of water system
- Probabilistic metrics (uncertainty)
- Multi-dimensional nature (complexity)

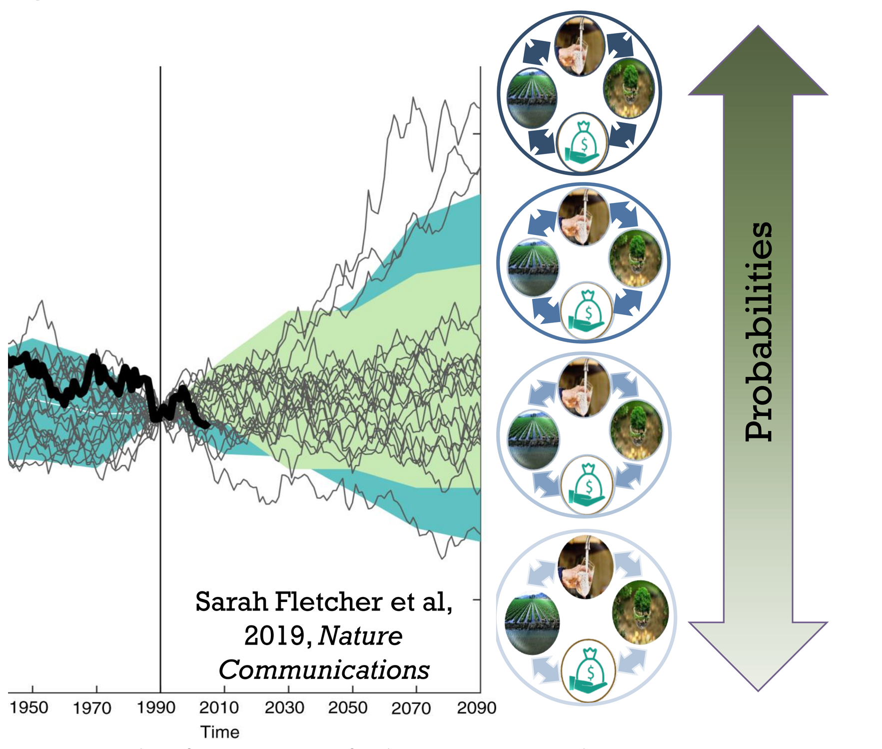

Fig1: comprehensive framework of climate change risk assessment

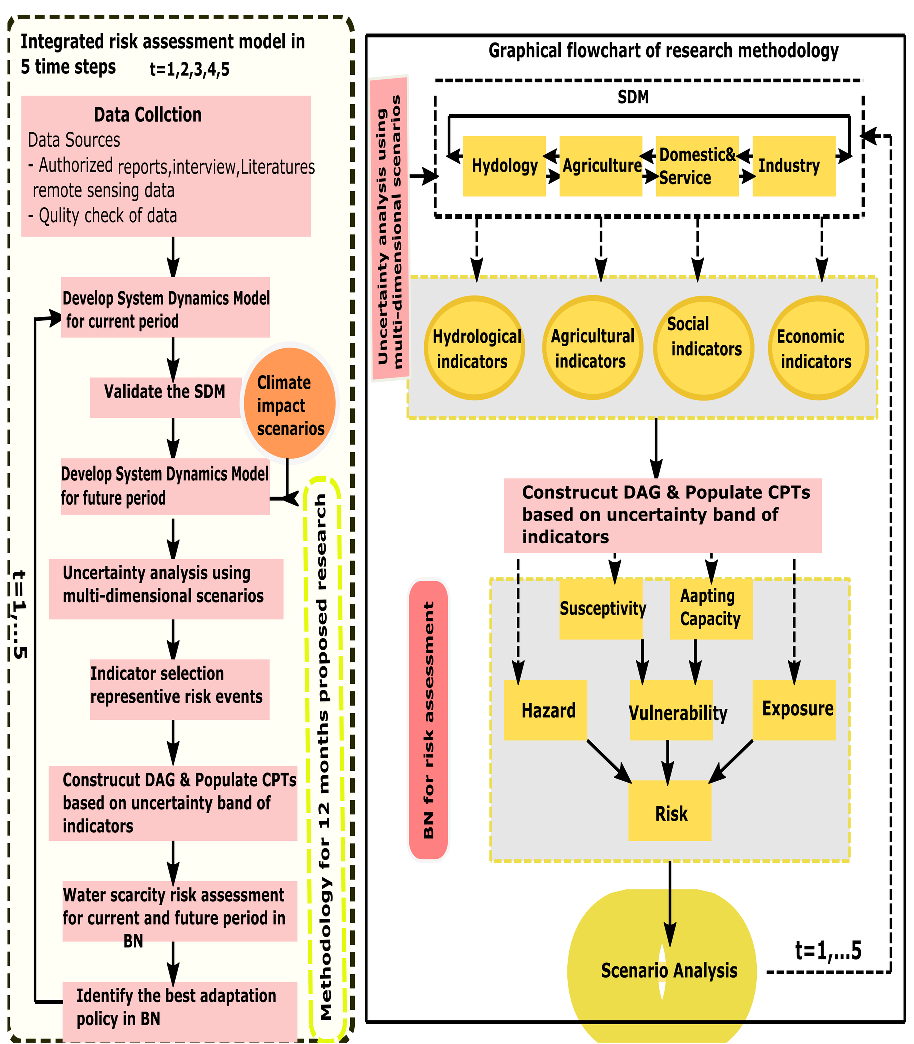

Fig 2: flowchart of integrated risk assessment

Methods

1. Good qualitative understanding of the water system
2. SDM Simulation of water system in current period
3. Extract SDM indices that are drivers of risk
4. Construct Bayesian Network based on SDM indices
5. Couple SDM -BN to evaluate the risk
6. Run SDM -BN model for future, using climate models
7. Present holistic view of the water system and related risks to decision makers

Case study and related issues

- Qazvin plain is located in the middle north of Iran with area of about 9550 km2.
- Water use for domestic, service, industry and agricultural sections is satisfied by surface water (rivers) and groundwater (wells, qanat and springs).
- Rain does not fall evenly over the plain but in highly localized spots (Naderi, 2021).
- The main sustainable source of groundwater supply is the Qazvin aquifer (Fig3).
- The withdrawal is 75% of the total water use in the region, mainly for agriculture.
- The fragility of water resources in the region, with increasing demand, result in an overexploitation of groundwater tables.
- SDM was built in three main subsystems including: Hydrological, Agricultural and, Socio-economic.
- SDM construction was done as follows:

(1) articulating the problem and defining the system boundary;

(2) developing a conceptual model or causal loop diagrams (CLD) of the system

(3) developing stock and flow diagram (SFD) to build a simulation model;

(4) model validation;

(5) generating scenario; Iran water authorities

(6) analyzing the results of different scenarios.

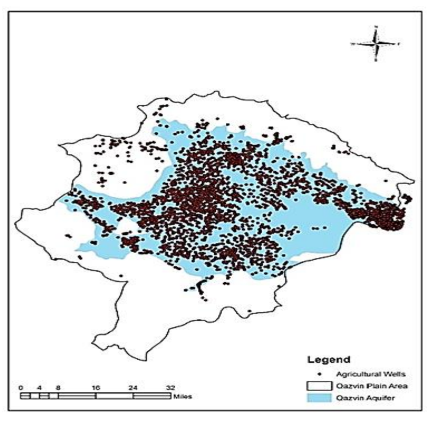

Fig3a: Agriculture wells locations

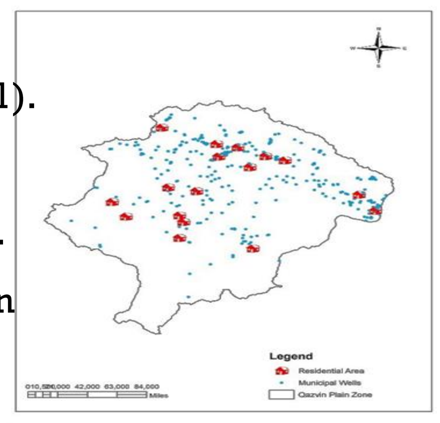

Fig3b: Domestic wells locations

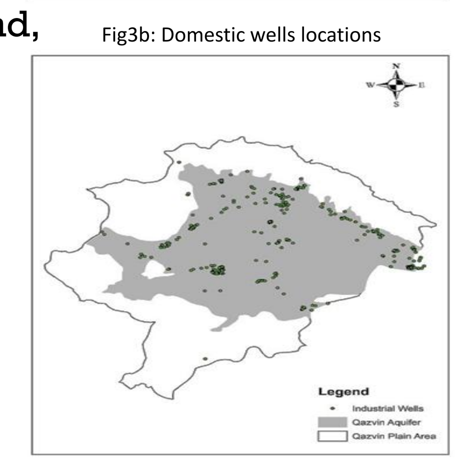

Fig3c: industrial wells locations, Ref: Iran water authorities

Result and discussion

- The increasing demand was fulfilled by groundwater withdrawal that resulted in a drastic decline of aquifer storage (Fig4 (a)).
- The simulation results depict regarding the SDM simulation, the agriculture subsystem is the first water user in the region (by more than 90% water use, Fig (4b))
- The results in agriculture simulation depicted there is significant difference between crops water requirement and agriculture water demand (Fig 4c).
- This difference is rooted in the lack of sufficient modern irrigation technologies in the area. Although traditional irrigations methods have low efficiency (30-40%) the modern irrigation systems have an efficiency of about 65-80%.

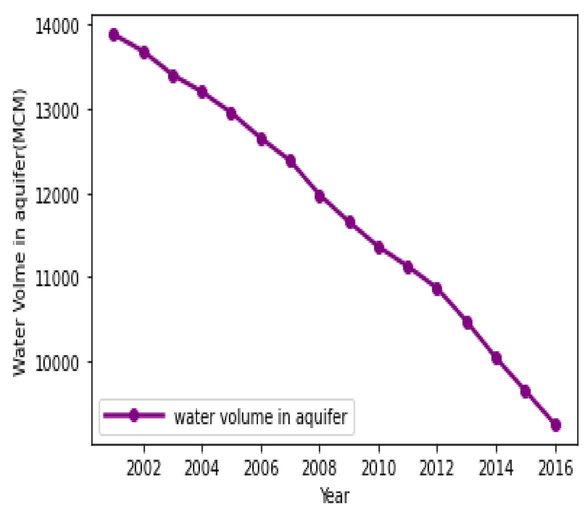

Fig4a: drastic decline in aquifer water volume due to over withdrawal

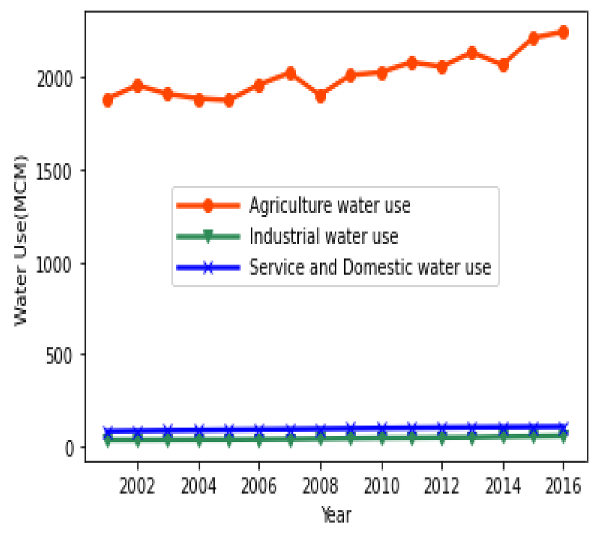

Fig4b: agriculture subsystem is the largest water user in the plain

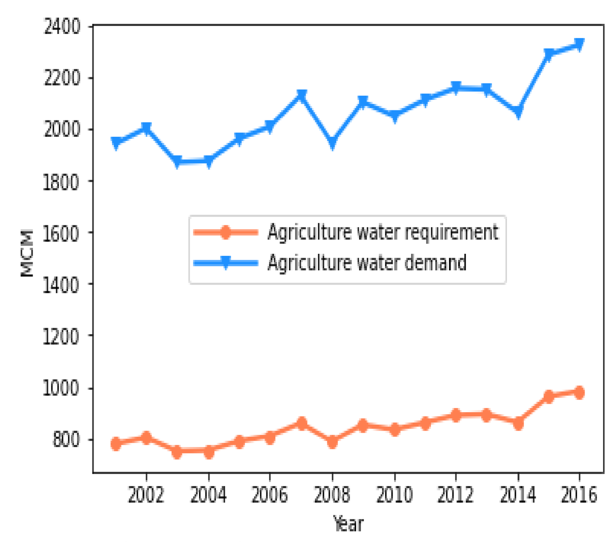

Fig4c: agriculture water demand and Crop requirement difference due to low Irrigation efficiency

- To establish BN for calculating the risk as a function of the risk components that define hazards, exposures and vulnerabilities, appropriate indicators selected from SDM to describe the trends of components of risk over the past and in future projections
- Potential risk component indicators are:

✓ *Hazard*: water scarcity (ratio of water demand to water use)

✓ *Vulnerability:* Vulnerability is an aggregation of physical and socio-economic factors including water use, economic profit, literacy rate, institutional resilience like insurance, economic development represented in GDP, farmland area, technological advancement.

✓ *Exposure*: As agriculture part is the main water user in the area, agricultural labor is the main exposed element to water scarcity due to decrease irrigated area based on the water-scarce situation.

- After formulating the risk component indicators, the BN is set up by defining conditional probability tables for each BN node.

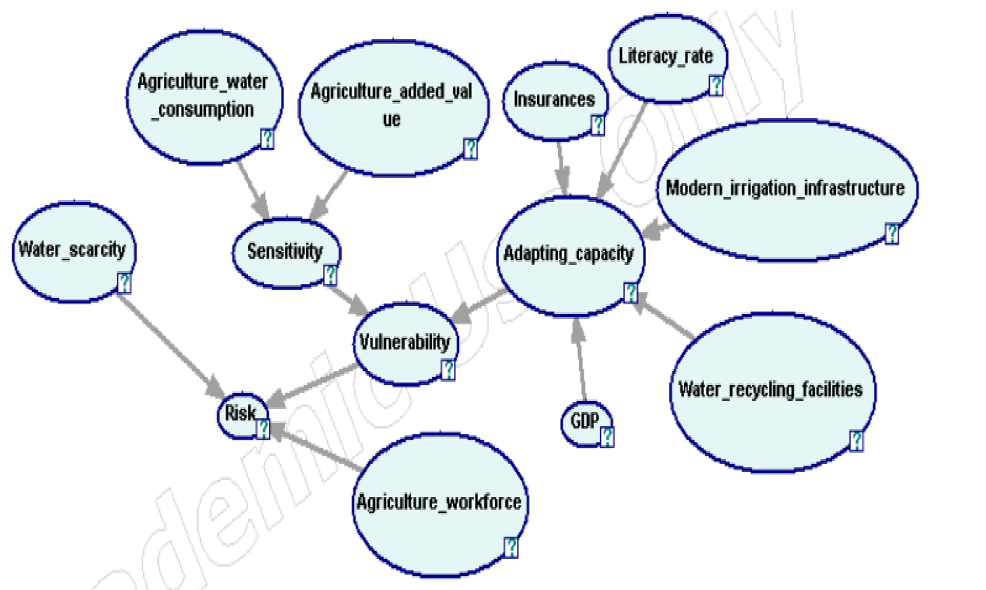

Fig5: integrated risk assessment using BN

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