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Participatory fuzzy cognitive mapping analysis to evaluate the future of water in the Seyhan Basin

Erol H. Cakmak, Hasan Dudu, Ozan Eruygur, Metin Ger, Sema Onurlu and Özlem Tonguç

ABSTRACT

Stress on the water resources of Turkey is expected to increase in the near future. This paper presents the results of a case study in one of the most important water basins in Turkey, the Seyhan Basin, where the future of the basin is estimated using a fuzzy cognitive mapping technique applied at a participatory meeting with the stakeholders. Participants envisioned that water supply, water demand and water use would decline in the future in response to the increasing impact of climate change. Improvements in sustainable water management, irrigation efficiency and the use of water-saving technologies will diminish the severity of scarcity that is expected to occur due to climate change.

Key words | dynamic analysis, fuzzy cognitive maps, Seyhan Basin, sustainable water management, water

Erol H. Cakmak (corresponding author)
Department of Economics, TED University,
Ziya Gokalp Cd. No. 48, Kolej, 06420, Ankara,
Turkey
E-mail: *erol.cakmak@tedu.edu.tr*

Hasan Dudu
Özlem Tonguç
Department of Economics,
Middle East Technical University, Ankara,
Turkey

Ozan Eruygur
Department of Economics,
Gazi University, Ankara,
Turkey

Metin Ger
Department of Civil Engineering,
Istanbul Aydin University, Istanbul,
Turkey

Sema Onurlu
Sintek Muhendislik Ltd, Ankara,
Turkey

INTRODUCTION

Water is designated as a scarce economic resource by the international community for at least two decades. The increase in irrigated land area in the 20th century has been considered as the major reason behind the scarcity. Changes in the volume, time, space and distribution of rainfall attributed to climatic change have also been effective in exerting significant pressure on water resources. This has led to significant shifts in the focus of researchers. Analysing the issues on irrigation water management and developing better policies and practices in a global scale have become priorities (Dudu & Chumi 2008).

This paper reports the findings of a qualitative scenario development process implemented in the Seyhan Basin, Turkey, as a part of the Water Scenarios for Europe and for Neighbouring States (SCENES) project. SCENES uses an integrated approach by combining and balancing several dimensions of issues related to water to address complex questions about the future of water resources in Europe, the Mediterranean and the Caucasus and Ural Mountains. SCENES adopts an iterative process for scenario enrichment on three levels: the pan-European scale, the regional scale and the basin scale. The enrichment works in both directions from pan-European to basin scales, and from basin to pan-European scales iteratively (Kämäri *et al.* 2008). This study is a part of the iterative process at the basin level. Seyhan is selected as one of the pilot areas to develop storylines and to feedback the upper level scenarios interactively.

In this context, stakeholder workshops are organized in the Seyhan Basin with the aim to identify their perception on the issues and drivers, and the interactions between the issues and the drivers. The data gathered are used to envision the future of water in the basin. Fuzzy cognitive maps (FCMs) are formed that represent the present and the

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estimated future states of the variables obtained through a dynamic analysis of the data.

OVERVIEW OF WATER IN TURKEY AND SEYHAN BASIN

Turkey has a water potential of 501 km^3, of which 274 km^3 is lost to evapotranspiration and evaporation. Approximately, 69 km^3 feeds aquifers and 158 km^3 flows to seas and lakes. Surface run-off is 193 km^3, but only 98 km^3 is usable. Out of this 98 km^3, 31 km^3 is consumed. Ground water recharge of 41 km^3 is added to surface run-off to supply a total of 234 km^3 of renewable water potential. With the estimated safe yield of ground water resources of 14 km^3, the total usable net water resources adds up to 112 km^3. Total consumption sums up to 43 km^3, of which 12 km^3 is supplied by ground water resources (Cakmak *et al.* 2008). Of this consumption, 75% belongs to the agricultural sector to irrigate approximately 5.28×10^6 ha of land (approximately 60% of the total economically and technically feasible irrigable area and 23% of the total cultivated area) (DSI 2009). Almost all of the irrigation schemes are managed by farmers, either in the form of Water User Associations (WUAs) or as Village Communities (VCs). Irrigation water is priced on a per hectare basis in Turkey. The average price of irrigation is around 70 Euro/ha (DSI 2006a).

Current stress on water resources of Turkey at the national level is considered to be moderate, but it is expected to increase significantly in the near future with the increasing competition for water between agricultural and non-agricultural use (Henrichs & Alcamo 2001; Alcamo *et al.* 2007; Cakmak *et al.* 2008). Furthermore, current irrigation management policies of Turkey are 'far from forming an integrated framework for effective management of water resources' (Cakmak *et al.* 2008). The need to develop a vision about the issues related to the state of water resources in Turkey is urgent if the policy makers intend to take the necessary measures to avoid the possible negative impact of increasing stress on water resources.

The Seyhan Basin is located in the eastern Mediterranean region. The Seyhan River, which is formed by the confluence of the Zamantı and Göksu Rivers, drains the Çukurova plain, which is one of the most important agricultural production areas of Turkey, and discharges to the Mediterranean Sea. The basin consists of 20,450 km^2 of land and an average water flow of 8.01 km^3 (DSI 2007a). The total irrigated area is about 271,000 ha, which is around 45% of the total cultivated area in the region (DSI 2006a; TURKSTAT 2009). The irrigation ratio is quite high compared to the national average of 23%. Almost all irrigation schemes are managed by WUAs, and only 15% of the irrigable area is rain fed.

The area of harvested land in the Seyhan Basin accounts for slightly more than 3% of the total harvested area in Turkey (Table 1). On the other hand, 4% of total agricultural value added is produced in the Seyhan Basin. The share of the Seyhan Basin in production rises as high as 11% for oil seeds and 7% for cereals. The most distinguishing characteristics of the Seyhan Basin are reflected in the crop yields. The national averages of yields are around 70% of yields in the Seyhan Basin. This ratio is as low as 50% (indicating the fact that yields in the Seyhan Basin are twice the overall average) for pulses. The Seyhan Basin is also important in vegetable and fruit production, for which the share of the Seyhan Basin in national production is around 5%.

Regional population growth rates and the ratio of urban to rural population are depicted in Tables 2 and 3. The figures show that the Seyhan Basin is highly urbanized. The ratio of urban to rural population is significantly higher than the national average. Rural population is

Table 1 | Shares of Seyhan Basin in total and relative yields, 2008

	Cultivated area (%)	Harvested area (%)	Production (%)	Ratio of yields (Turkey/ Seyhan)
Total crops	3.21	3.39	3.88	0.70
Pulses	1.36	1.58	1.57	0.50
Industrial crops	6.51	6.52	1.78	0.72
Cereals	2.83	3.01	6.66	0.72
Oil seeds	7.71	7.73	10.74	0.93
Feed crop	0.75	0.78	1.02	0.74
Tuber crops	3.20	3.21	4.42	0.64
Vegetables	N.A.	N.A.	4.90	N.A.
Fruits	1.84	N.A.	4.91	0.44

Source: TURKSTAT (2009).

Table 2 | Annual average population growth rates (%)

	Seyhan Basin			Turkey		
	Total	Urban	Rural	Total	Urban	Rural
1975	1.82	2.03	1.37	1.68	1.88	1.48
1980	1.82	1.81	1.83	1.61	1.75	1.47
1990	1.41	1.51	−1.25	−1.26	−1.28	−1.23
2000	−1.16	1.13	−1.37	1.52	1.66	1.11
2008	1.33	1.50	−1.59	1.24	1.47	−1.49

Source: TURKSTAT (2009).
Note: The averages are calculated on a compound basis.

Table 3 | Ratio of urban population to rural population

	Seyhan Basin	Turkey
1970	1.03	0.62
1975	1.32	0.72
1980	1.31	0.78
1990	2.31	0.75
2008	6.71	2.99

Source: TURKSTAT (2009).

Table 4 | Dams in Seyhan Basin

Dam	Setup year	Normal volume (hm^3)	Irrigation area (ha)	Power (MW)	Annual production (GWh)
Berke	1999	427		510	1,672
Çatalan	1997	2,126		169	596
Kesiksuyu	1971	53	8,760		
Kozan	1972	170	10,220		
Nergizlik	1995	22	2,326		
Seyhan	1956	1,200	174,000	59	350
Arıklıkaş	1998	1,872	285		
Aslantaş	1984	1,150	149,849	138	569
Kalecik	1985	33	4,890		
TOTAL		7,053	350,330	876	3,187

Source: DSI (2009).

Table 5 | Irrigated land in Seyhan Basin, 2001–2008

	Irrigated land (ha)	Total cultivated land (ha)	Share of irrigated land (%)
2001	250,279	581,459	43.04
2002	258,405	576,388	44.83
2003	264,381	612,645	43.15
2004	306,224	595,996	51.38
2005	279,457	594,363	47.02
2006	279,113	562,195	49.65
2007	267,332	554,265	48.23
2008	270,965	555,427	48.79

Sources: DSI (2004, 2005, 2006b, 2007b, 2008); TURKSTAT (2009).

declining consistently, while urban population is increasing. The population in the region is increasing faster than the national average as a result of migration from the eastern regions of Turkey.

There are six dams in the basin. Four of these dams are used specifically for irrigation. Their water holding capacity adds up to 4,500 hm^3, with an irrigation capacity of about 350,330 ha (Table 4). Although the irrigated area steadily increases in the basin, its share in the total cultivated area has not changed much in the last decade (Table 5).

Effects of climate change are expected to be significant in the Seyhan River Basin (Cline 2007; Nagano *et al*. 2007; Fujihara *et al*. 2008b). Expected decline in annual precipitation changes between 25–29% (Fujihara *et al*. 2008a) and 42–46% (Nagano *et al*. 2007) for 2070, according to general circulation models. The decrease is projected to occur in wintertime (Nagano *et al*. 2007). As a result, the frequency of critical flood events will decline, while that of critical droughts will increase under climate change (Fujihara *et al*. 2008b). Evapotranspiration is likely to decline by 9–10% (Fujihara *et al*. 2008a), which is likely to cause the shallow water table to lower (Nagano *et al*. 2007). The level of ground water is likely to decline due to overuse of ground water sources (Fujinawa *et al*. 2007), and its quality will deteriorate significantly because of salinization, which will be caused by excessive irrigation (Nagano *et al*. 2007) and sea-level rise (Fujinawa *et al*. 2007). Salinization is already an important problem in the Seyhan Basin, affecting 31% of the irrigated area (Kanber & Ünlü 2008). Piped drainage systems seem to be a promising alternative to reduce salinity (Fayrap *et al*. 2008).

Water scarcity will not be a problem if the irrigation area is not expanded (Fujihara *et al*. 2008a) in the Lower Seyhan Basin Irrigation Project. Even under huge decreases in precipitation, the irrigation capacity would be enough for the Seyhan Basin (Nagano *et al.* 2007; Selek *et al.* 2008).

Turkey is expected to be one of the few countries where per capita water availability exceeds the threshold in 2025 (Brochier & Ramieri 2001). Water availability in the Seyhan Basin is higher than the national average, but current water-use efficiency in the region is as low as 40% (Kanber *et al.* 2005; Nagano *et al.* 2007), and increasing the efficiency by good management practices is crucial to prevent water scarcity (Fujihara *et al.* 2008a). Deficiency of the rotation system implemented by WUAs is identified as one of the underlying reasons for the low irrigation efficiency (Efe *et al.* 2008). Water scarcity in the drought years may cause the irrigation efficiency to be as low as 20% (Selek *et al.* 2008). WUAs play a key role in water conservation by implementing practices that will ensure water conservation by farmers (Kütük & Saatçı 2008).

The role of irrigation water management is crucial in adapting the effects of climate change (Fujinawa *et al.* 2007; Fujihara *et al.* 2008a). Management of irrigation water and land use would have larger influences on the shallow water table than on climate change (Nagano *et al.* 2007). Although the transfer of management responsibilities to locally controlled organizations seems to bear promising results in terms of operational and maintenance cost recovery, fee collection and participatory management (Yazar 2002), there is significant room for reorganization due to unfavourable management practices of some WUAs (Umetsu *et al.* 2007). Pricing of water seems to be an important tool in conserving water resources (Umetsu *et al.* 2007). However, WUAs do not use any systematic approach in setting water prices (Kütük & Saatçı 2008; Önder *et al.* 2008). Furthermore, WUAs seem to have significant income losses due to their inability to collect the fees from farmers (Kütük & Saatçı 2008).

The Seyhan Basin may have a large adaptive capacity towards climatic and social changes (Nagano *et al.* 2007). Deficit irrigation can be a water-saving and yield-increasing alternative to current irrigation methods (Ünlü *et al.* 2008). Drip irrigation can also be a serious alternative, not only for water saving, but also for fertilizer saving (Özekici 2008), if investment costs can be reduced or agricultural value added can be increased (Kanber *et al.* 2005). It is possible to save 42% of irrigation water in pressurized systems (Coşkun 2008). Adequate pricing of water, changing the conventional irrigation and production techniques, and proliferation of drought resistant crop types are among the most emphasized adaptation strategies in the literature (Kapur *et al.* 2008).

SETTING OF THE PARTICIPATORY MEETING, MAIN ISSUES AND THE CURRENT STATE

A meticulous selection of the stakeholders that will enable a fair representation was necessary in order to obtain a meaningful picture of the future of water in the Seyhan Basin. The participants were from diverse interest groups. Representatives from central and local public institutions related to water and agriculture, environmental and farmers' non-governmental organizations (NGOs), irrigation associations and the local university participated in the workshop.

The workshop was conducted both in forum and group settings, depending on the issue that was covered. In forum settings, participants were asked to convey their individual perceptions, whereas in group settings, reaching consensus on the discussed issue was required. Pre-prepared forms were used for both processes. Filled forms reflected either individual or group consensus. Collected data were immediately processed, and the results were then shared with the participants. Homogeneous groups were formed to save time in reaching consensus, but the results obtained from the groups were finalized in a forum discussion. The groups formed by the stakeholders were:

1. training and academic personnel;
2. technocrats and bureaucrats;
3. farmers and irrigation associations; and
4. NGOs.

Despite the fact that many of the participants were not used to this kind of meeting and there was a considerable amount of work to do within a specified time, the attendance of the participants remained high throughout the workshop.

The identification of the main issues/drivers was necessary to start the FCM analysis. Participants were first given a list of predetermined issues identified by the researchers during their prior visits to the basin area. The list was formed by a combination of social, economic and environmental issues that may be crucial in water shortage (Table 6).

However, the participants were not restricted with the predetermined list. They were encouraged to contemplate and add any missing issues. Eventually, the participants came up with a list of 32 variables with the context of the issues precisely defined. It was encouraging to note that there were not many divergent views on the issues. Almost all participants agreed on the relevance of both the predetermined issues and the ones that were added by other participants during the process.

Participants were then divided into four groups to decide on the most important issues in the list. A final list of the top 15 issues was decided according to the ratings provided by the participants (Table 7).

Following the establishment of the final list of variables, it was necessary to determine the present state of the selected variables. The participants were asked to assign weights to each variable on a scale from one to five individually, and the outcome was discussed in a group setting. The scaling was as follows: 1 – null, 2 – very small, 3 – small, 4 – big and 5 – very big. This corresponds to a modified spidergram practice. The assigned values represent the relative position of the designated variable with respect to its desired level (Figure 1).

Table 6 | List of predetermined issues

Issues			
01	Rate of recycled waste water	14	Water demand
02	Impact of increasing urbanization	15	Use of water-saving methods
03	Maintenance, repair and overhaul	16	Irrigation infrastructure
04	Environmental consciousness	17	Irrigation water pollution
05	Drainage problem	18	Irrigation water use
06	Internal migration	19	Price of irrigation water
07	Impacts of climate change	20	Irrigation efficiency
08	Employment	21	Sustainable water management
09	Decrease in forestry	22	Agricultural support policies
10	Impact of industrial production	23	Increase in agricultural output
11	Water supply	24	Salinity
12	Water delivery losses	25	Ground water use
13	Support for publications on water use		

Source: Workshop results.

Table 7 | Final list of variables/drivers

Variables/drivers			
D01	Impact of increasing urbanization	D09	Irrigation water use
D02	Water supply	D10	Irrigation efficiency
D03	Water demand	D11	Water pollution
D04	Irrigation water price	D12	Use of water-saving methods
D05	Agricultural support policies	D13	Sustainable water management
D06	Impacts of climate change	D14	Soil degradation
D07	Water delivery losses	D15	Use of ground water
D08	Irrigation infrastructure		

Source: Workshop results.

The averages of the input from four groups for each variable were further discussed in a forum setting. Educational and academic personnel were generally more optimistic while the farmers sketched a rather pessimistic view about the present state of the variables. However, divergence was not significant among the groups. The main issues where the divergence of views was relatively high were: water demand (D03), water use (D09) and use of water-saving technologies (D12). Farmers thought that the first two (D03 and D09) were adequate, while NGO representatives believed that the last one (D12) was far from being satisfactory. Agricultural support (D05) and use of water-saving technologies (D12) and sustainable water management (D13) were considered to be far less satisfactory when compared to the desired level.

METHODOLOGY

FCMs are 'fuzzy-graph structures that are used to model hazy causal relationships between different concepts' (Kosko 1986). An FCM is composed of nodes, which represent the concepts, and edges, which stand for the causal

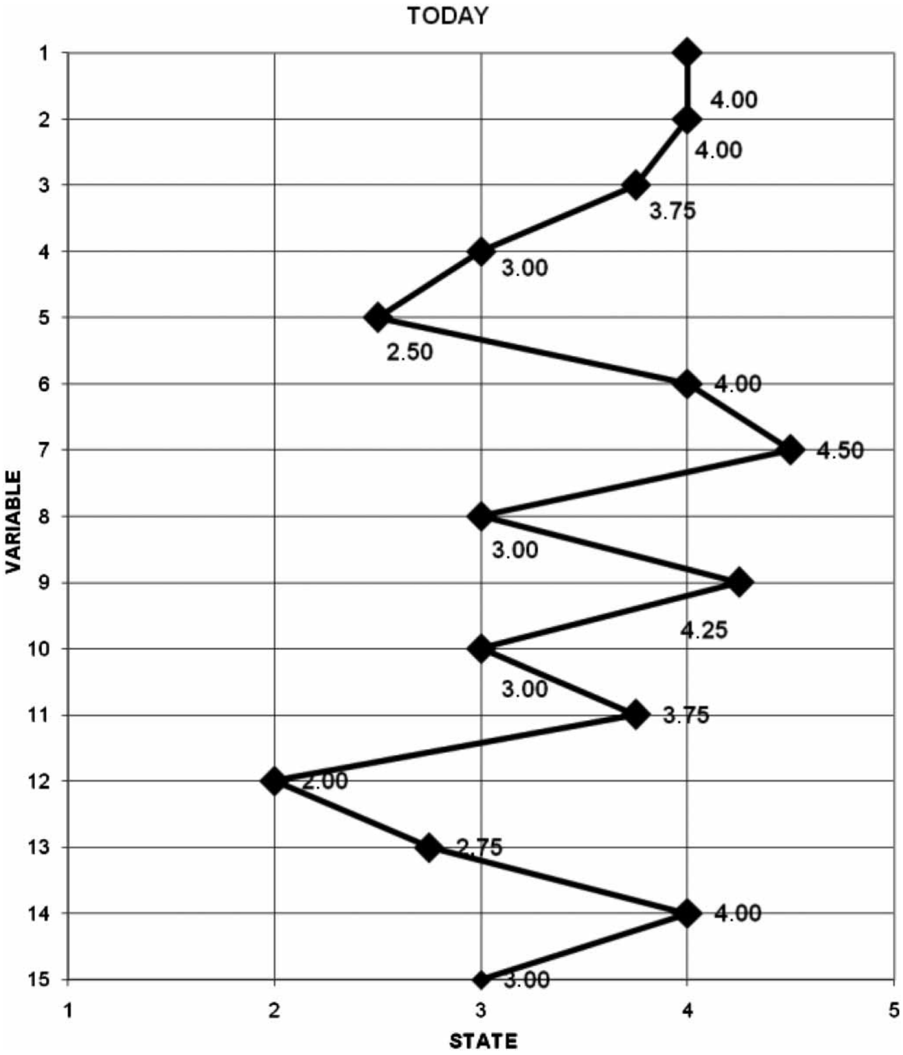

Figure 1 | Overall ratings of the issues in the present state. *Source*: Workshop results.

relationships between the concepts, as in Figure 2. This graphical representation can be expressed with a state matrix that shows the initial status of the concepts and a weight matrix that shows the causal relationships. The cell (i, j) of weight matrix shows the strength of the causal relationship between concept i and concept j. The sign of the weight shows the direction of the causal relationship such that a positive weight implies that concept i reinforces the current status of concept j, while a negative weight implies that concept i impedes the current status of concept j. The weight matrix is iteratively multiplied by the state vector of which the ith element shows the perceived status of concept i. The resulting vector shows the relative state of the concepts in the future under the causal relationships described by the weight matrix (van Vliet *et al.* 2010).

FCMs are used in various contexts from ecological systems to producing intelligent decision-making engines. Siraj *et al.* (2004) use FCMs and fuzzy-rule bases to create a decision engine that detects intrusions to a computer system. Sharif & Irani (2006) use fuzzy cognitive mapping and morphological analysis to formulate a conceptual model of decision-making behaviour within the information systems evaluation task. Özesmi & Özesmi (2004) use FCMs to create ecological models with both expert and local people's knowledge. Similarly, there are studies in the literature where FCMs are used to model political developments

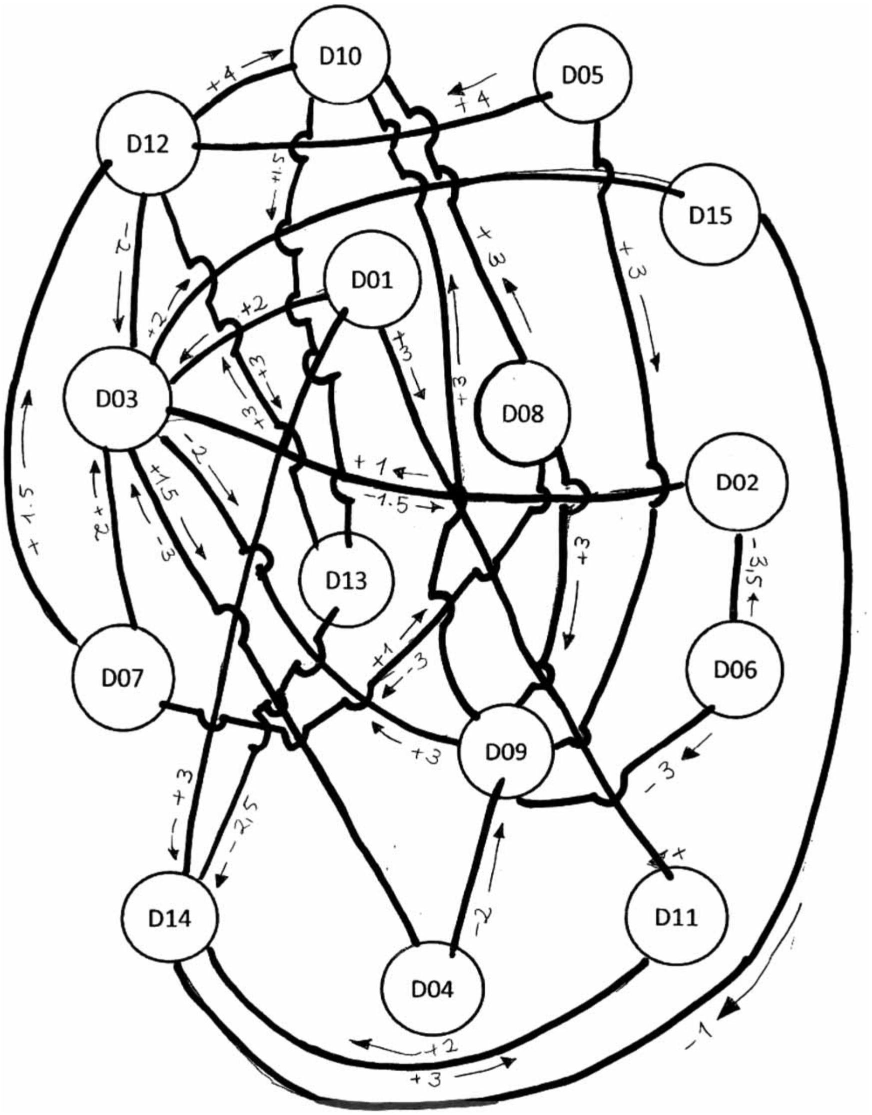

Figure 2 | Final FCM.

(Taber 1991), electrical circuits (Styblinski & Meyer 1988) and virtual worlds (Dickerson & Kosko 1994).

Recently, FCMs have been widely used to facilitate public participation by modelling local and expert knowledge. Studies that utilize FCMs in such a fashion include Özesmi (2006), where FCMs are used to map social and economic conditions of local people before their resettlement due to a dam construction. Kastens & Newig (2008) study active involvement of regional stakeholders in northwest Germany in effective implementation of the Water Framework Directive (WFD). Mouratiadou & Moran (2007) use FCMs to model stakeholder and public perceptions on water-related issues in a river basin in Greece, thereby promoting the involvement of stakeholders and the public for successful implementation of the WFD. Özesmi & Özesmi (2003) use FCMs to create a participatory management plan for a lake ecosystem.

The formulation of the FCM for the problem at hand is of the following form:

$$S_{i,t} = A_{ij}^{T} S_{i,t-1}$$

where $S_{i,t}$ represents the value of the state of the variables and A_{ij} is the transition matrix that represents the direction and strength of the interconnection between the variables.

The calculation rule, as depicted in the above equation, is that the previous values of the states of the variables, $S_{i,t-1}$, are involved in determining the new values of the states of the variables, $S_{i,t}$.

In order to ensure convergence in FCM iterations, it is necessary to normalize the state vector. Normalization is carried out according to the formula:

$$s'_j = \frac{s_i - \dfrac{\sum_i s_i}{n}}{\sum_j S_j - \dfrac{\sum_j s_j}{n}} \tag{1}$$

where s_i is the ith element of the state vector before normalization, s'_i is the normalized value of s_i and n is the total number of variables.

We have also rescaled the elements of the transition matrix to the 0–1 interval according to:

$$A'_{ij} = \frac{A_{ij}}{\max(A_{ij})} \tag{2}$$

where A_{ij} is the element of the transition matrix A in the ith column and jth row. A'_{ij} is the normalized value of A_{ij}.

In the dynamic analysis, it is highly possible not to have convergence or very slow convergence, since the construction of the FCMs relies heavily on human experience and knowledge. In order to direct a system to a desired steady state, several methods are used. Learning algorithms are one of the methods used for this purpose. A learning algorithm basically determines the weights and outlines the convergence to reach a desired steady state via local search techniques. When applied to the case of FCMs, this process corresponds to updating the strengths of interconnections (Papageorgiou *et al.* 2004).

To enhance convergence, the elements of the state vector at each step are weighted as:

$$S_t = \left(\frac{1}{\max\left(\mathrm{abs}\left(\min\left(s'^{\in S_{t-1}}_{i,t-1}\right)\right),\ \max\left(s'^{\in S_{t-1}}_{i,t-1}\right)\right)}\right) S'_{t-1}A' \qquad \text{for } t = 2\ldots T \tag{3}$$

where S_t is the state vector at step t of the iterations and $s'^{\in S_{t-1}}_{i,t-1}$ is the ith element of the normalized state vector S'_{t-1} at iteration $t-1$. S_t is normalized at each step according to Equation (1). A' follows from Equation (2).

In order to have a realistic FCM, it was decided to limit the number of variables to seven with the modified nonlinear Hebbian learning algorithm. Our approach in the mechanism was to focus on seven key variables: water supply (D02), water demand (D03), impacts of climate change (D06), irrigation water use (D09), use of water-saving technologies (D12), sustainable water management (D13) and irrigation efficiency (D10). In implementing the algorithm, however, instead of comparing all possible combinations of subsets of seven variables, the seven-element subsets that contain these two variables were compared, since the impacts of climate change (D06) and sustainable water management (D13) have relatively 'stronger' links. Among the possible 1,287 possible subsets, implementation of the algorithm yielded the subset that contains variables 'water supply (D02), water demand (D03), impacts of climate change (D06), irrigation water use (D09), use of water-saving technologies (D12), sustainable water management (D13) and irrigation efficiency (D10)' to be the most appropriate subset.

Even though the FCM constructed using the subset of variables identified above converges to a new stable state, to further enhance the convergence, all variables are assumed to be affected mildly by its present state. That is, in the state of having a transition matrix with zero diagonal values, all the diagonal elements were set equal to 0.25.

RESULTS AND DISCUSSION

For the FCM analysis, the participants were asked to create two desired future state vectors for 2015 and 2030. Every group assigned desirable values for each of the 15 variables for the two future dates. Average values for each variable were first calculated, and then finalized with a discussion in the forum setting. The future state vectors are compared with the results of FCM analysis to check the consistency of the results. The results are given in Table 8.

A declining trend in the impact of increasing urbanization is observed. This shows that the participants expect urbanization effects to be weaker in the future, which is consistent with the observations about the demographic

Table 8 | Current and future states of variables

	Today	2015	2030		Today	2015	2030
Impact of increasing urbanization	4.00	2.53	1.75	Irrigation water use	4.25	4.00	4.18
Water supply	4.00	4.33	4.65	Irrigation efficiency	3.00	4.45	4.85
Water demand	3.75	3.75	4.20	Water pollution	3.75	1.93	1.08
Irrigation water price	3.00	3.08	3.13	Use of water-saving methods	2.00	3.75	4.43
Agricultural support policies	2.50	3.95	4.55	Sustainable water management	2.75	4.07	4.88
Impacts of climate change	4.00	2.13	1.58	Soil degradation	4.00	1.83	0.98
Water delivery losses	4.50	1.65	1.28	Use of ground water	3.00	2.28	1.63
Irrigation infrastructure	3.00	4.30	4.95				

Source: Workshop results.
Note: All values in the table show assigned weights to each variable on a scale from 1 to 5 (1: null, 2: very small, 3: small, 4: big, 5: very big).

dynamics of the region. Water supply, water demand and water price increase in time, suggesting a possible shift of agricultural production to the water-intensive crops that create higher value added. However, irrigation water use does not change significantly, while use of ground water sources declines considerably. This is consistent with decline in water pollution and soil degradation, as well as increasing irrigation efficiency, water delivery losses and use of water-saving methods. Improvements in irrigation infrastructure, agricultural subsidies and sustainable water management are the key drivers for these enhancements.

To finalize the FCMs, the participants were asked to individually fill the matrices provided where they defined weights and direction for the relationships among the selected issues. Average values were calculated for each entry, and the results were presented to the participants. Afterwards, the participants were again divided into four groups, where they were asked to further discuss the matrices. Five FCMs were obtained as a result of this process: four FCMs from each group representing their group perception as the representatives of the stakeholders, and one FCM that the attendants of the workshop produced through their collective wisdom. The finalization of the overall FCM (Figure 2) was achieved in a forum setting by asking for evaluation to confirm the directions of the links and assign final weights to these links.

No facilitators were assigned to the groups, but, in any case, participants seemed to handle the FCM framework well. Since the groups were homogeneous, cognitive and social learning was limited, but this was a necessary sacrifice due to the time constraint. Designated relationships among the issues in the transition matrix are presented in Table 9. A variable in the first column of the table affects a variable in the second column. The size of the effect is given in the last column. A negative number in the last column implies a negative relationship between the variables. That is, as the level of the variable in the first column of the table increases, the level of the variable in the second column of the table decreases, and vice versa.

Most of the relationships in the table are as expected. One unexpected relationship occurred between water supply and water demand. According to the results, water supply increases water demand, while water demand decreases water supply. Participants may have thought that availability of more water will encourage the cultivation of more water intensive crops, resulting in an increase in water demand. Participants may have also believed that as demand increases, irrigation water usage will decline. This recalls an explanation by the competition between farmers such that if demand by all farmers increases, the amount of water available for any farmer will decline.

The outcome of dynamic analysis is given in Figure 3. All variables are stabilized in the interval of 1 and −1, which shows that the system gives comparable and meaningful results. Dynamic analysis shows that, at the end of the iterations, only irrigation efficiency and sustainable water management maintain their levels in the state vector. All other variables are expected to be in a lower state compared to their initial state.

Table 9 | Relationship between issues used to form the transformation matrix

Affecting issue	Affected issue	Size of effect
Impact of increasing urbanization	Water demand	2
Impact of increasing urbanization	Soil degradation	3
Impact of increasing urbanization	Water pollution	3
Water supply	Water demand	1
Impacts of climate change	Water supply	−3.5
Water demand	Water supply	−1.5
Water demand	Irrigation water use	−2
Water demand	Use of ground water	2
Water demand	Irrigation water price	1.5
Irrigation water price	Water demand	−3
Water delivery losses	Water demand	2
Use of water-saving methods	Water demand	−2
Irrigation water price	Irrigation water use	−2
Agricultural support policies	Irrigation water use	3
Agricultural support policies	Use of water-saving methods	4
Impacts of climate change	Irrigation water use	−3
Water delivery losses	Use of water-saving methods	1.5
Water delivery losses	Irrigation infrastructure	1
Irrigation infrastructure	Water delivery losses	−3
Irrigation infrastructure	Irrigation efficiency	3
Irrigation infrastructure	Irrigation water use	3
Irrigation water use	Irrigation efficiency	3
Irrigation water use	Water demand	3
Use of water-saving methods	Irrigation efficiency	4
Irrigation efficiency	Sustainable water management	1.5
Water pollution	Soil degradation	2
Soil degradation	Water pollution	3
Use of water-saving methods	Sustainable water management	3
Sustainable water management	Use of water-saving methods	3
Sustainable water management	Soil degradation	−2.5
Use of ground water	Soil degradation	−1
Use of water-saving methods	Impacts of climate change	3

Source: Workshop results.

Note: Values in the table show assigned weights to the relationship between variables on a scale from −5 to +5 (−5: strongly negative … − 1: weakly negative, 0: none, +1: weakly positive … + 5: strongly positive).

Accordingly, the impact of urbanization will decline in the future. This is consistent with the declining urbanization rates observed in long-term time series. Water supply and water demand will decline, resulting in a decline in the use of water in irrigation. Increasing impact of climate change is probably the underlying dynamic for declining water supply and demand. The decline in supply is compensated with more sustainable water management practices. This is supported by the relatively high levels of irrigation efficiency, lower soil degradation and less use of underground water, as well as declining water delivery losses. Decline in the irrigation infrastructure calls for more investment.

As mentioned in the methodology section, we introduced a learning mechanism for a limited subset of the key variables to obtain a better picture of the FCMs. The final results are depicted in Figure 4. The series labelled as '2009' shows the current state vector. '2030/Estimated' shows the results of FCM analysis, while '2030/Desired' shows the values of the future state vector that is obtained directly from the participants. The results with the learning mechanism amplify the picture obtained with the full set of variables. Participants expect a decline in water supply, water demand and, consequently, water use. Improvements in the states of efficiency, water-saving technologies and sustainable water management will be the major dynamics underlying the changes in demand, supply and use. Hence, the ultimate effects of climate change will decrease.

Our findings in the FCM framework suggest that increasing water efficiency and water saving through more investment in irrigation infrastructure will decrease the water demand, and this will compensate the decline in the water supply due to climate change. Ultimately, the impact of climate change will decrease and quality of water and land resources will improve.

In a study very similar to ours, Mouratiadou & Moran (2007) use FCMs to elicit stakeholder and public perceptions on the current state and pressures on water resources and the acceptability of applying economic principles in water resource management. Based on these perceptions, different water management policy options are simulated in order to explore their potential effects on the water resources and the economy of the area. FCMs are demonstrated to be a useful

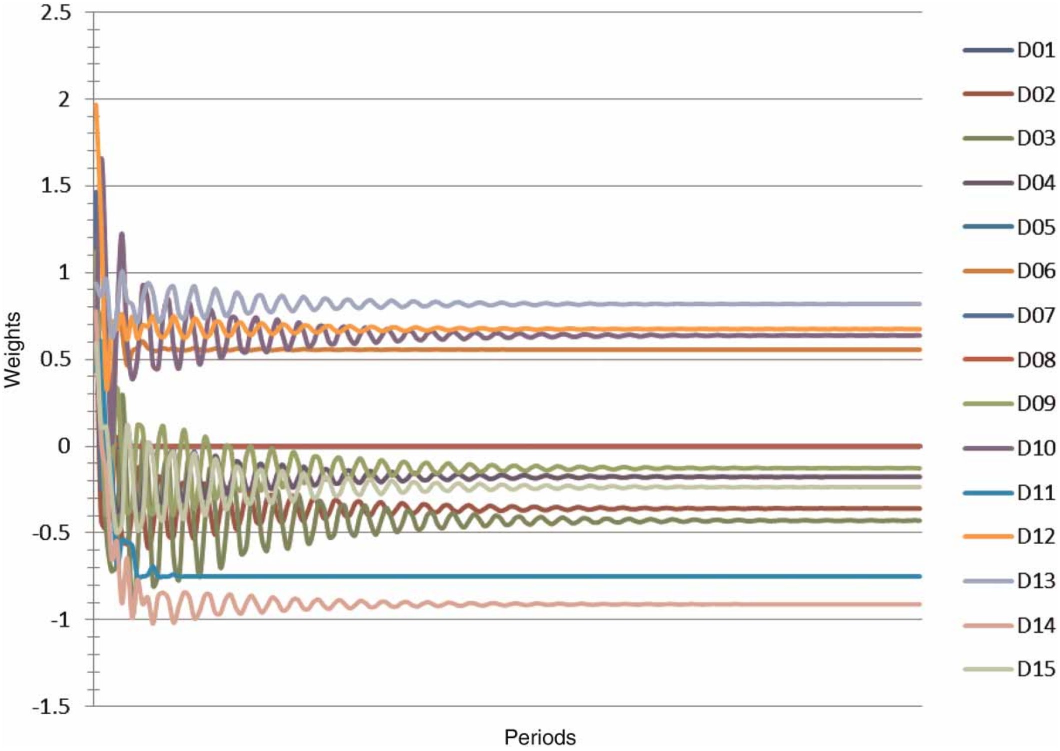

Figure 3 | Results of the FCM analysis. *Source*: Authors' calculations from the results of the workshop. *Note*: Values on the vertical axis show calculated weights on a scale from −5 to +5 (−5: strongly negative … − 1: weakly negative, 0: none, +1: weakly positive … + 5: strongly positive).

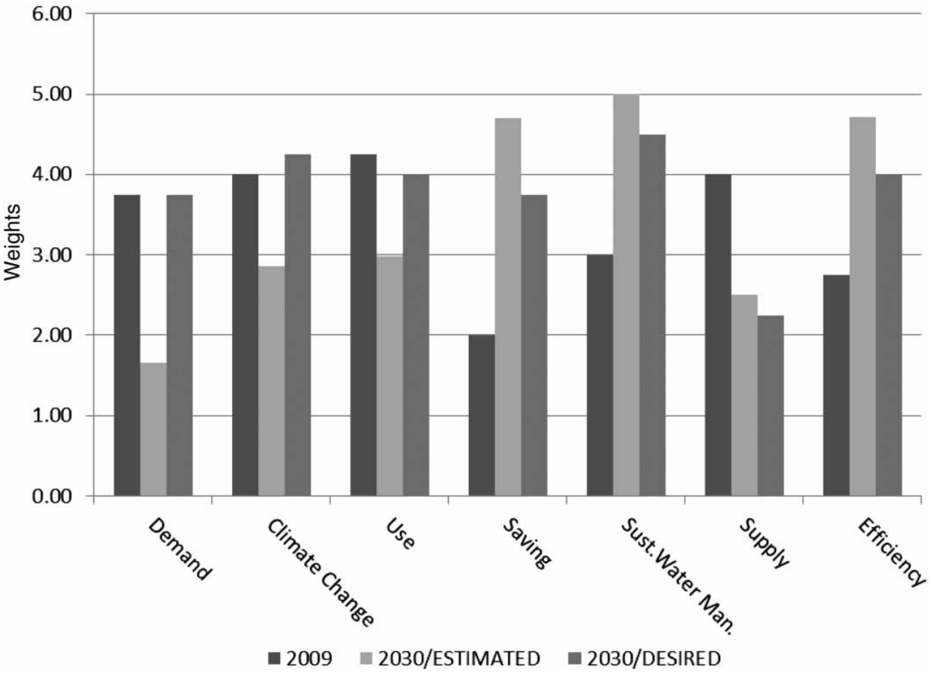

Figure 4 | Results of dynamic FCM analysis with learning. *Source*: Authors' calculations from the results of the workshop. *Note*: Values on the vertical axis show calculated weights on a scale from 0 to 5 (0: none … 5: very big).

tool for capturing stakeholder understanding of the system and their perception on the water pricing requirements of the European Union Water Framework Directive.

Fuzzy cognitive mapping has been utilized to model diverse problems involving dynamic systems, ranging from agroforestry management to policy formulation to recover from natural hazards. Kok (2009) introduces FCMs as a possible improvement to the story-and-simulation approach. His application to the Brazilian Amazon illustrates that by involving an integrated set of factors and feedbacks, FCMs can capture (future) dynamics of deforestation. He concludes that the example substantiates the tool's capacity to improve the consistency of narrative storylines and the diversity of quantitative models. On the other hand, the tool was designed to be simple and therefore has important drawbacks. Future improvements should be made in the light of applications within a larger toolbox of scenario methods.

In a recent study, Murungweni *et al.* (2011) investigate the characteristics and drivers of rural livelihoods in the Great Limpopo Transfrontier Conservation Area in southern Africa to assess the vulnerability of inhabitants who are subject to various hazards. FCMs are applied to analyse the vulnerability and resilience of social-ecological systems since the FCM methodology allows analysis of both direct and indirect feedbacks and therefore can be employed to explore the vulnerabilities of livelihoods to identified hazards. They claim that FCMs successfully present information concerning the nature (raise or decline) and magnitude by which a livelihood system changes under different scenario simulations. This shows that FCMs are able to recover hidden knowledge and provide insights that improve the understanding of the complexity of livelihood systems in a way that is better appreciated by stakeholders.

Another application is by Hobbs *et al.* (2002), who propose encoding expert knowledge about interactions among ecosystem components in an FCM, which then translates that subjective, qualitative information into predictions of the effects of management on an ecosystem. They claim that the use of the FCM method promotes constructive interaction among dozens of scientists, managers and the public, as well as providing insights concerning the potential effects of broad classes of management actions upon the concerned ecosystem.

Özesmi & Özesmi (2004) use a multi-step fuzzy cognitive mapping approach to create ecological models with both expert and local people's knowledge. Their research includes analysing the perceptions of different stakeholders in an environmental conflict, obtaining the perceptions of various stakeholders to ease the development of participatory environmental management plans, and determining the wants and desires for resettlement of people displaced by a large-scale dam project. They emphasize that fuzzy cognitive mapping offers many advantages for ecological modelling, including the ability to involve abstract and aggregate variables in models, the ability to model interactions that are not certainly known, the ability to represent complex relationships that are full of feedback loops, and the ease and speed of obtaining and combining different knowledge sources and of running different policy options.

Samarasinghea & Strickert (2013) emphasize that the integration of physical and social sciences for model development is important to advance our capacity to understand and deal with the complex world. They use an FCM-based auto-associative neural network framework generated from a development mixed-method integration for adaptive policy formulations. Their findings show the potential of the mixed-method triangulation-based FCM computational modelling framework for transparent policy refinement through iterative engagement of stakeholders for increasing their collective and adaptive capacity in preparation for, response to, and recovery from natural hazards.

CONCLUSION

In this paper, we have presented the findings of a modified dynamic FCM framework analysis on water-related issues in the Seyhan Basin, Turkey. The main outputs of the participatory process were the determination of the issues and drivers, and their interaction using FCMs, and thus to determine future expectations for better water management. In the current state, agricultural support, use of water-saving technologies and sustainable water management are considered to be far less satisfactory compared to their desired level. Dynamic analysis shows that, at the end of the iterations, only irrigation efficiency and sustainable water management maintain their levels in the state vector. All other variables are expected to be in a lower state compared to their initial state.

Final results suggest that participants expect a decline in water supply, water demand and, consequently, water use. Improvements in the states of efficiency, water-saving technologies and sustainable water management will be the main dynamics underlying the changes in demand, supply and use. The analysis shows that the stakeholders are fully aware of the potential impact of climate change, and they can identify effective adaptation strategies to lessen the possible negative impact of climate change on the region.

One of the major contributions of this study is the enhancement of the versatility of the FCM technique, which is a powerful tool to define the plausible future of cases with the number of drivers by coupling it with a participative process in order to accommodate for the perception of the stakeholders. That is, the future state of each and every driver is constructed by not only taking into consideration the interrelationships of the drivers, but also through the consensus of the stakeholders on the present and the future states.

The combined implementation of FCMs and participation techniques applied to the future of water issues, as mentioned in the methodology and discussion sections, is not solely limited to similar problems in other regions of the world, but is applicable to a wider range of issues whenever multiple stakeholder involvement is a necessity.

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