

Game theory and fuzzy programming approaches for bi-objective optimization of reservoir watershed management: a case study in Namazgah reservoir

N. Üçler · G. Onkal Engin · H. G. Köçken · M. S. Öncel

Received: 3 June 2014 / Accepted: 28 January 2015 / Published online: 18 February 2015
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Abstract In this study, game theory and fuzzy programming approaches were used to balance economic and environmental impacts in the Namazgah reservoir, Turkey. The main goals identified were to maximize economic benefits of land use and to protect water quality of reservoir and land resources. Total phosphorous load ($\text{kg ha}^{-1} \text{ year}^{-1}$) and economic income ($\text{USD ha}^{-1} \text{ year}^{-1}$) from land use were determined as environmental value and economic value, respectively. The surface area of existing land use types, which are grouped under 10 headings according to the investigations on the watershed area, and the constraint values for the watershed were calculated using aerial photos, master plans, and basin slope map. The results of fuzzy programming approach were found to be very close to the results of the game theory model. It was concluded that the amount of fertilizer used in the current situation presents a danger to the reservoir and, therefore, unnecessary fertilizer use should be prevented. Additionally, nuts, fruit,

and vegetable cultivation, instead of wheat and corn cultivation, was found to be more suitable due to their high economic income and low total phosphorus (TP) load. Apart from agricultural activities, livestock farming should also be considered in the area as a second source of income. It is believed that the results obtained in this study will help decision makers to identify possible problems of the watershed.

Keywords Reservoir watershed management · Game theory · Fuzzy programming · Bi-objective optimization

Introduction

Environmental problems caused by industrial activities, rapid population growth, unplanned agricultural activities, inadequate infrastructure, and untreated wastewater can affect water resources negatively. This situation creates the need for an effective management of water resources. Watershed planning and management generally deal with single objective problems, such as hydropower generation or flood control (Turoğlu 2005; State Hydraulic Works 2007). However, watershed development and planning activities should be approached as a multi-objective problem, so that all the stakeholders would get optimum benefit.

Generally, it is difficult for the decision makers to choose an appropriate action from the alternatives of watershed management because it is necessary to select a feasible and acceptable action for all stakeholders who have different views and interests. Possible conflicts occurring between the ones who care for economic income and the ones who are concerned with environmental issues should be solved at bureaucratic level (Lund and Palmer 1997).

Watershed models are used to predict future impacts of management plans for implementing sustainability in watershed management. The Stanford Watershed Model (SWM) is

Responsible editor: Michael Matthies

N. Üçler · M. S. Öncel
Department of Environmental Engineering, Gebze Technical University, 41400 Gebze, Turkey

N. Üçler
e-mail: nadireozel@gmail.com

M. S. Öncel
e-mail: soncel@gyte.edu.tr

G. O. Engin (✉)
Faculty of Civil Engineering, Department of Environmental Engineering, Yildiz Technical University, Esenler, 34220 Istanbul, Turkey
e-mail: guleda@gmail.com

H. G. Köçken
Faculty of Chemistry-Metallurgy Engineering, Department of Mathematic Engineering, Yildiz Technical University, Esenler, 34220 Istanbul, Turkey
e-mail: hgonce@yildiz.edu.tr

accepted as the first watershed hydrological model and was created in the mid-1960s (Crawford and Linsley 1966). Watershed models have evolved from purely engineering/economic models to more integrated models that include data processing and management tools such as geographic information systems (GIS) and database management systems (Singh and Woolhiser 2002). Watershed models may be classified according to their scope and purpose into four categories (Mirchi et al. 2009): engineering-based watershed process models (Chen et al. 1982; Abaci and Papanicolaou 2007; Wang et al. 2009; Habarth and Barkdoll 2009), hydro-economic models (Lund and Ferreira 1996; Draper et al. 2003; Jenkins et al. 2004; Maneta et al. 2009), multi-criteria (multi-objective) decision-making models (Duckstein and Opricovic 1980; Gershon and Duckstein 1983; Wen and Lee 1998; Lamy et al. 2002), and conflict resolution models (Rogers 1969; Lee and Chang 2005; Lee 2012).

Eutrophication is a problem caused by an increase in concentration of nutrients in aquatic ecosystems. Because of high nutrient concentrations, eutrophication is a major problem in many Turkish river basins (Karpuzcu et al. 2006). Watershed protection application plan studies have been started to improve the water quality levels in the 26 river basins by the Ministry of Forestry and Water Works and there are other studies conducted on water quality in Turkey (Esen and Uslu 2008; Erturk et al. 2010; Hadjikakou et al. 2011). However, game theory and fuzzy programming approaches have not been used previously in watershed management in Turkey. In this paper, game theory and fuzzy programming approaches were used to balance economic development and environmental impact in the Namazgah reservoir watershed located in the northwestern part of Turkey.

Material and methods

Multi-objective model for reservoir watershed management

The multi-objective model can be stated as follows:

$$\max \text{ or } \min E(x) = [E_1(x), E_2(x), \dots, E_v(x),] \tag{1}$$

Subject to:

$$g_j \leq 0, j = 1, 2, \dots, m;$$

$$x_k \geq 0; k = 1, 2, \dots, n;$$

where $E(x)=[E_1(x),E_2(x),\dots,E_v(x),]$ is a set of all v objective functions, $g_j(x)$ is the j th constraint function, and x_k is the k th decision variable.

Since the solution of the multi-objective model is Pareto-optimal, the goal is to find the Pareto-optimal solutions of Eq. (1).

Watershed management has many stakeholders and, therefore, multiple objectives due to its nature. These objectives can be social, economic, and environmental, such as reduction of nutrients and minimization of water pollution, maximization of the water and soil conservation, and maximization of the economic gain resulting from land use. In addition, in the case of reservoir watershed management modeling, it is very common to handle the multi-objective model Eq. (1) as a bi-objective model, i.e., having two main objectives. These objectives are the maximization of economic development and the minimization of environmental impact. In this paper, both game theory and fuzzy programming approaches were used to solve this bi-objective model.

Game theory approach for reservoir watershed management

Game theory is a mathematical method to solve the allocation problems related to conflicting situations, which was developed by Von Neumann and Morgenstern (1944). This interactive decision-making process attempts to identify optimal strategies at equilibrium between several players who make choices that affect the interests of other players (Davila et al. 2005; Parrachino et al. 2006). To apply the game theory model to the RWM problem, two stakeholders were selected as players, as given below:

Player 1: ecologist player

Player 2: economist player

The purpose of the player 1 was the minimization of environmental impact (the solution of land use types minimization of environmental impact) and can be given as,

$$\text{MinTP} = E_1(x) \tag{2}$$

The purpose of the player 2 was the maximization of economic development (the solution of land use types maximization of economic development) and can be expressed as,

$$\text{MaxIC} = E_2(x) \tag{3}$$

Thus, the last form of the bi-objective model can be stated as follows:

$$\text{MinTP} = E_1(x) \tag{4}$$

$$\text{MaxIC} = E_2(x)$$

Subject to:

$$g_j \leq 0, j = 1, 2, \dots, m;$$

$$x_k \geq 0; k = 1, 2, \dots, n;$$

To determine the negotiation interval of the game, individual maximum and minimum values were calculated for each player by solving a traditional linear programming problem.

Therefore, the range of the maximum and minimum values (total phosphorus (TP), economic income (IC)) for each player was determined as follows:

$$TP_{\min} \leq TP = E_1(x) \leq TP_{\max} \tag{5}$$

$$IC_{\min} \leq IC = E_2(x) \leq IC_{\max} \tag{6}$$

Once the range was known, the initial round of bargaining began and each player had a strategy:

For the player 1, the strategy was as follows:

$$\text{MinTP} = E_1(x) \tag{7}$$

such that,

$$\begin{aligned} g_j &\leq 0, j = 1, 2, \dots, m; \\ E_2(x) &\geq IC_{\text{goal}} \\ x_k &\geq 0; k = 1, 2, \dots, n; \end{aligned}$$

And for the player 2:

$$\text{MaxIC} = E_2(x) \tag{8}$$

such that,

$$\begin{aligned} g_j &\leq 0, j = 1, 2, \dots, m; \\ E_1(x) &\leq TP_{\text{goal}} \\ x_k &\geq 0; k = 1, 2, \dots, n; \end{aligned}$$

Two players started the first round of bargaining. At the first bargaining round, the players chose strategy which was very close to their goal (TP_{min} and IC_{max}). But players were not satisfied with the results, and the second round of bargaining started. Then, player 1 lowered the environmental expectation, while player 2 lowered the economic income expectation.

To determine the concession value of each player, max and min values of TP and IC were divided into small equal pieces. The concessions were increased at each round.

Determination of concession:

$$\text{Concession 1} = \frac{TP_{\max} - TP_{\min}}{n} \tag{9}$$

$$\text{Concession 2} = \frac{IC_{\max} - IC_{\min}}{n} \tag{10}$$

such that,

n is a coefficient that provides the most reasonable concession value which will not drop much the satisfaction value of both players

During the bargaining process, the difference between strategies and the results became less different. The bargaining

rounds continued until final solutions are reached (TP_{final}, IC_{final}).

$$TP_{\text{final}} \leq TP_{\text{goal}} \tag{11}$$

$$IC_{\text{final}} \geq IC_{\text{goal}} \tag{12}$$

These TP_{final} and IC_{final} values are known as the equilibrium values (Osborne and Rubinstein 1994; Gibbons 1997).

Fuzzy programming approach for reservoir watershed management

The fuzzy programming approach is a widely used technique to solve a bi-objective decision-making problem. In this technique, the aim is to find a compromise solution that maximizes the satisfaction degree of all membership functions, after constructing the membership functions of the objectives.

The individual maximum and minimum values of objectives (TP_{min}, TP_{max}, IC_{min}, IC_{max}) can be used to define the membership functions of the problem (4). In this study, for the sake of simplicity, linear membership functions were used. Then, the membership function of environmental impact was constructed as follows:

$$\mu_1(E_1(\mathbf{x})) = \begin{cases} 1 & , \text{if } E_1(\mathbf{x}) < TP_{\min} \\ \frac{TP_{\max} - E_1(\mathbf{x})}{TP_{\max} - TP_{\min}} & , \text{if } TP_{\min} \leq E_1(\mathbf{x}) \leq TP_{\max} \\ 0 & , \text{if } E_1(\mathbf{x}) > TP_{\max} \end{cases} \tag{13}$$

where TP_{max} ≠ TP_{min}. If TP_{max} = TP_{min}, then μ₁(E₁(x)) = 1. The membership function μ₁ is strictly monotonous decreasing in the interval of [TP_{min}, TP_{max}].

And similarly, the membership function of economic development was constructed as follows:

$$\mu_2(E_2(\mathbf{x})) = \begin{cases} 0 & , \text{if } E_2(\mathbf{x}) < IC_{\min} \\ \frac{E_2(\mathbf{x}) - IC_{\min}}{IC_{\max} - IC_{\min}} & , \text{if } IC_{\min} \leq E_2(\mathbf{x}) \leq IC_{\max} \\ 1 & , \text{if } E_2(\mathbf{x}) > IC_{\max} \end{cases} \tag{14}$$

where IC_{max} ≠ IC_{min}. If IC_{max} = IC_{min}, then μ₂(E₂(x)) = 1. The membership function μ₂ is strictly monotonous increasing in the interval [IC_{min}, IC_{max}].

Using Zimmermann's minimum operator (Zimmermann 1991), the bi-objective model was written as:

$$\text{maxmin}\{\mu_1, \mu_2\} \tag{15}$$

subject to:

$$\begin{aligned} g_j(\mathbf{x}) &\leq 0 & , j = 1, 2, \dots, m \\ x_k &\geq 0 & , k = 1, 2, \dots, n \end{aligned}$$

By introducing an auxiliary variable λ , Eq. (15) can be transformed into the following equivalent conventional LP problem:

$$\begin{aligned} &\max \lambda && (16) \\ &\text{subject to:} \\ &\mu_1 \geq \lambda, \\ &\mu_2 \geq \lambda \\ &g_j(\mathbf{x}) \leq 0 \quad , j = 1, 2, \dots, m \\ &x_k \geq 0 \quad , k = 1, 2, \dots, n \\ &0 \leq \lambda \leq 1 \end{aligned}$$

Thus, Eq. (16) generates compromise Pareto-optimal solutions for the bi-objective model.

Case study

Kocaeli is an economically important province of Turkey because of intensive industrialization, tourism, and agricultural activities. Thus, the best evaluation of water and land resources both economically and environmentally is very important for decision makers.

The Namazgah Dam is under construction in order to provide potable water for a number of districts around Namazgah area. The main agricultural products are wheat and nuts in the Namazgah area. A small amount of corn, vegetables, and fruits are also cultivated. Livestock is another income source. The Food Specialized Organized Industrial Zone (FSOIZ) is also planned to be built within the boundaries of the basin. It is necessary to prepare a watershed management plan in order to protect the water quality in the dam, as it will be used as a source of drinking water. This study was conducted to determine the effects of the planned FSOIZ in the basin, to decide efficient uses of agricultural land, and to help resolve conflicts.

Namazgah reservoir watershed

The Namazgah reservoir watershed which is located in Kabaagac Village, Kandira in Kocaeli Province has a surface

area of 100.89 km². The reservoir was designed to store approximately 25 hm³ water with a surface area of 2.84 km². The annual runoff is 48.89 hm³ year⁻¹, and the max water depth is 60 m. The dam is still under construction and will start to keep water at the end of 2014. Most of the watershed’s area is covered with forest and agricultural lands. Major sources of income are agriculture and livestock.

Present situation in Namazgah watershed

After carrying out site surveys in the region, studying land use maps and aerial photographs, and interviewing local residents, it was decided that the land use in the watershed can be grouped under 10 main headings, as rural settlement, forests and woodlands, wheat, corn, nuts, vegetables and fruits, cultivated agricultural fields and uncultivated agricultural areas, dam area, and the planned industrial zone. In order to find out the surface areas of each type of land use, the aerial photographs taken in 2012 were used (Fig. 1).

The present situation of the land use in the watershed, the locations of the dam, streams, and the planned organized industrial zone can be seen in Fig. 2, and the percentage distributions can be found in Fig. 3.

Another important issue was to determine the total area of steep areas which are not suitable for settlements or agricultural activities. For this purpose, the slope map of Kocaeli region (Fig. 4) was used to determine the areas having a slope over 55 %. It was found out that there is no area with 55 % slope, and therefore, this was not defined as a constraint.

Determination of TP values

The water pollution sources can be grouped in two categories as point and non-point sources (Table 1). Since Namazgah Dam is constructed for potable water supply, it is assumed that point sources will not be permitted to reach the main water supply by the related water authority. Therefore, in this study, only non-point sources, which are difficult to monitor and control, were considered.

Some of the non-point sources listed in Table 1, such as urban runoff, atmospheric deposition, and solid waste

Fig. 1 Areas of existing land use patterns in the basin

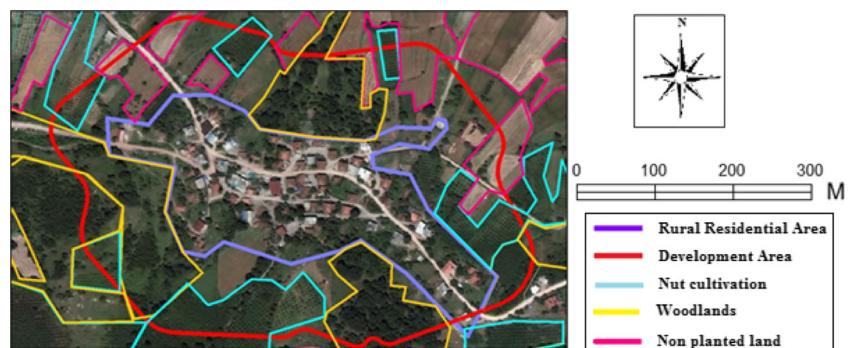
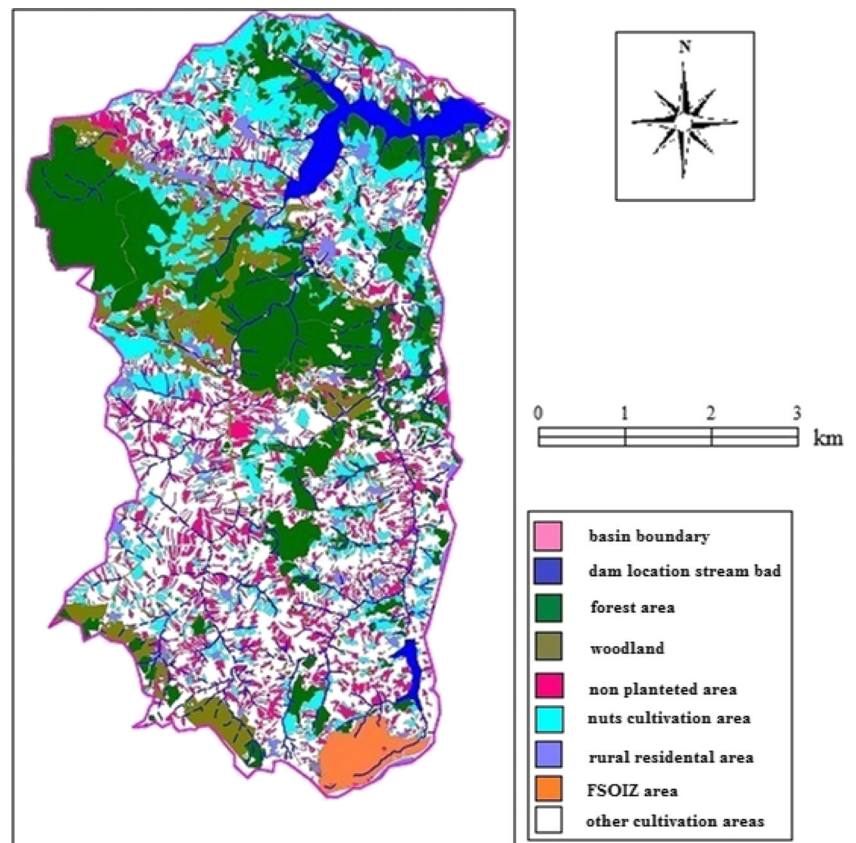


Fig. 2 Current land use situation of Namazgah reservoir watershed



leachates, were not considered in this study, as they do not constitute a problem for the selected watershed.

As known very well, there are a number of parameters affecting the water quality classification. The intercontinental surface water resource quality criteria classifications can be found in Table 2 (Ministry of Forestry and Water Affairs 2012). Since eutrophication is the most common reservoir water quality problem and phosphorus is the limiting nutrient

for eutrophication, TP was selected as the pollutant of interest for this study.

The main sources of pollutants in residential areas are the pollution due to livestock activities carried out within the residential area and the existing rural septic tanks. However, since the manure obtained from livestock activities is used as fertilizer in agricultural areas, the TP originated from livestock activities was not considered in TP calculations for rural areas. Likewise, as mentioned before, the current septic tanks will be connected to the newly constructed sewer system, and therefore, the TP load resulting from the septic tanks was not considered in TP calculations for rural areas. Although the forests and woodlands were evaluated under different categories, the same TP value was assigned to both forests and woodlands, as no economic return was expected. Uncultivated agricultural areas would be expected to become green over time due to rain and therefore were considered within the meadow grassland class. For rural residential areas, forest areas, woodlands, and uncultivated areas, the TP values used in some of the significant studies carried out in Turkey were found suitable (Dahl and Kurtar 1993; OEJV 1993; Saatci et al. 1999).

For agricultural lands, two types of TP load values were determined according to the current fertilizer use and the fertilizer that will be needed for each crop. The TP values of the current fertilizer use were determined by the consumption rate of commercial and animal fertilizers. The animals bred in the

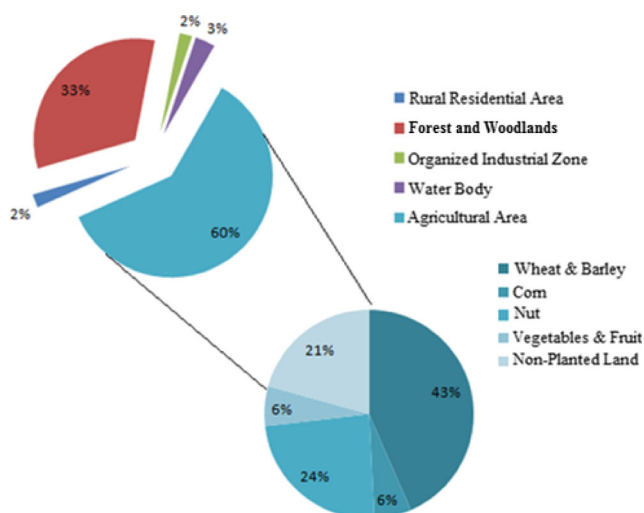
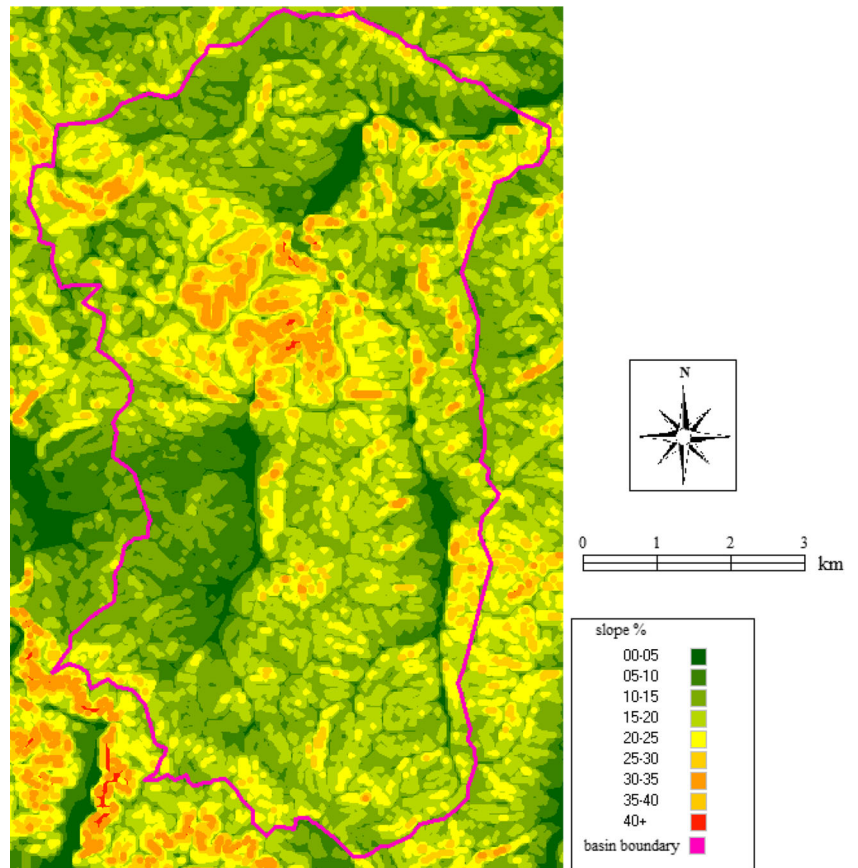


Fig. 3 Current land use situation

Fig. 4 Slope map of Namazgah reservoir watershed



basin were classified within three main groups such as cattle, sheep, and poultry. In order to calculate the amount of fertilizer derived from animal activity, the total number of livestock in the basin was obtained from the Village Service Department of the Kocaeli Metropolitan Municipality. Although it is known that the phosphorus loads may vary depending on a number of different parameters such as animal category, type, weight, and feeds used, the estimated values of TP load (kg/ton animal weight) of each group of animals given in the literature were used in the calculations (Table 3) (Agricultural

2001; Andreadakis et al. 2007; Ozturk et al. 2007b). The TP values per animal were calculated according to the assumptions that cattle, sheep, and poultry weights 500, 45, and 2 kg each, respectively.

As for the fertilizers, the amounts used in the district were obtained from the Kandira Provincial Directorate of Food, Agriculture and Livestock. It should be noted that only fertilizers having phosphorus content were considered in this study. The TP values were calculated using the P_2O_5 ratios (*w/w*) of the fertilizers used. The TP value from commercial fertilizers was calculated from the ratio of fertilized area of the Kandira district to fertilized area of the whole watershed. The TP constants were determined from the total amount received from the manure and commercial fertilizers per agricultural areas and per phosphorus needs for each agricultural product, accordingly. It was assumed that 5 % of TP originated from both manure and commercial fertilizers is received by the water media (Ozturk et al. 2007a). During the calculation of the TP constants, the phosphorus-containing fertilizer needed by each product was considered for the case of needed amount of fertilizer used for each product type. The TP values according to the fertilizer need of each crop were determined using the quantity of P_2O_5 used for each crop per year per hectare (Kacar and Katkat 1997).

Table 1 Main pollution sources

Pollutant sources	
Point sources	Non-point sources
<ul style="list-style-type: none"> ▪ Domestic wastewater discharges ▪ Industrial wastewater discharges ▪ Urban drainage systems discharge 	<ul style="list-style-type: none"> ▪ Loads resulting from agricultural areas ▪ Loads from livestock ▪ Loads resulting from forest areas ▪ Loads resulting from meadow, pasture and grazing land ▪ Urban runoff ▪ Rural runoff ▪ Atmospheric deposition ▪ Solid waste storage areas leachates ▪ Septic tank effluent

Table 2 Intra-continental surface water resource quality criteria classification Ministry of Forestry and Water Affairs (2012)

Water quality parameters	Water quality classes			
	I ^c	II ^d	III ^e	IV ^f
Temperature (°C)	≤25	≤25	≤30	>30
pH ^a	6.5–8.5	6.5–8.5	6.0–9.0	6.0–9.0
Conductivity (μS/cm)	<400	400–1,000	1,001–3,000	>3,000
Color ^b	0.8	1.7	2.5	2.8
Dissolved oxygen (mg O ₂ /L)	>8	6–8	3–6	<3
Chemical oxygen demand (COD) (mg/L)	<25	25–50	50–70	>70
Biological oxygen demand (BOD ₅) (mg/L)	<4	4–8	8–20	>20
Ammonium nitrogen (mg NH ₄ ⁺ -N/L)	<0.2	0.2–1	1–2	>2
Nitrite-nitrogen (mg NO ₂ ⁻ -N/L)	<0.002	0.002–0.01	0.01–0.05	>0.05
Nitrate-nitrogen (mg NO ₃ ⁻ -N/L)	<5	5–10	10–20	>20
Total Kjeldahl nitrogen (mg/L)	0.5	1.5	5	>5
Total phosphorus (mg P/L)	<0.03	0.03–0.16	0.16–0.65	>0.65
Total coliform (MPN/100 mL)	≤100	100–20,000	20,000–100,000	>100,000

^a Except between the values given^b Absorbance values measured at 620 nm^c High-quality water^d Slightly polluted water^e Polluted water^f Highly polluted water

It was reported that a wastewater treatment plant will be built in FSOIZ, and necessary measures will be taken to avoid both point and non-point loads in the Environmental Impact Assessment Report of FSOIZ (Ministry of Environment and Urbanization 2009). Therefore, the TP load that will originate from the FSOIZ was also neglected.

In order to determine the extent of the assimilation capacity of the reservoir to the phosphorus loads coming from the catchment, the Vollenweider method (Vollenweider 1976) was used. The equations used can be found in Eqs. 17 and 18.

$$L_c = P_{\lambda,c} \times q_s \times (1 + T_w) \quad (17)$$

$$Y = L_c \times A \quad (18)$$

Where,

- L_c Critical load (μg phosphorus /m² year)
 $P_{\lambda,c}$ Critical concentration of phosphorus (μg/m³)
 q_s Hydraulic load (m/year)
 z Average depth (m)
 T_w Hydraulic retention time (year)
 A Lake area (km²)
 Y Assimilative capacity of the reservoir (kg/year)

The necessary parameters for the abovementioned Vollenweider method were obtained from the characteristics

Table 3 TP load assumptions for each group of animal types

Animal species	TP tons/animal weight/day	TP kg/animal/year
Cattle	0.1	18
Sheep-goat	0.06	1
Poultry	0.22	0.2

determined for the dam project. The values used and the calculation results can be seen in Table 4.

Determination of IC values

The income values for agriculture lands were calculated annually using the data which were obtained from the Provincial Directorate for Food, Agriculture and Livestock. The cost statements of the cultivated products, sales prices, and product yields were provided by the abovementioned authority. In addition, the IC values were derived separately for each product, considering the product, diesel, and seed subsidies given by the state. The annual income per hectare of forest area was obtained from the Forest District Directorate. The income values of woodlands and non-planted areas were neglected. The income value of FSOIZ was calculated using the data which was taken from the report prepared by the East Marmara Development Agency (2011). Since the industrial area is still in the planning stage, it is difficult to mention a net worth of economic benefits. However, the important role of the industrial area in

Table 4 The necessary parameters for the Vollenweider method used and the assimilative capacity of the reservoir

Parameters	Units	Values
z	m	53.00
$P_{\lambda,c}$	μg/L	30.00
T_w	year	0.57
q_s	m/year	92.45
L_c	μg/m ² year	4,873.27
A	km ²	2.84
Y	kg/year	13,855.00

the economic growth is stressed in the Food Specialized Organized Industrial Zone Report, and therefore, an approximate IC value was determined accordingly. The income value of water body was calculated using the data which were taken from the Namazgah Reservoir Environmental Impact Assessment Report (Ministry of Environment and Urbanization 2011).

The income value of rural residential areas was calculated using livestock data. In this region, stock farming, sheep and goat breeding, and chicken farms are major livestock forms. Cattle numbers were obtained from the Breeding Union. To determine the amount of milk obtained from one cow, a number of interviews were carried out with farm owners, veterinarians, and the university’s veterinary department. The cost of one liter of milk was determined by taking the average results of the past studies carried out in different regions (Murat 2011). The cost was then updated accordingly. Income derived from milk was calculated using the cost and sale price of 1 l of milk in the region. The income resulting from cattle was calculated using cattle slaughter rates. For the calculation of the income from sheep and goat breeding, a survey was conducted with the farm owners, and the average profit was calculated. To determine the capacity of chicken farms and the profit per animal, interviews with farm owners were the main calculation point. The pollutant (TP) load and economic income (IC) according to major land use types are listed in Table 5.

Constraints

The constraints of the watershed were defined using the land availability of the watershed, current situation of residential areas, agricultural lands, forest areas, and the limit values specified in the regional development plan and phosphorus assimilative capacity of reservoir. The constraints defined are as follows:

- The minimum and maximum rural residential areas (based on current situation and regional development plan)

- The forest areas (kept as the current situation, so that the area of forests does not fall under the current situation and that a non-applicable solution, such as conversion of agricultural lands to forest area, would not be obtained).
- The minimum woodland areas (based on the current situation)
- The minimum and maximum agricultural areas (based on current agricultural areas and their usage)
- The minimum water body (determined according to the total area of Sarnıçlar and Kocakaymaz ponds and the reservoir)
- The maximum FSOIZ area (determined from the area allocated for the FSOIZ in the urban and regional plans)
- The phosphorus assimilative capacity (calculated using the Vollenwider method)
- The watershed area (sum of land use area must be equal to watershed area)
- The value of any land use cannot be negative

The bi-objective model for the Namazgah reservoir can be formulated as follows:

Objectives:

1. TP load

For current fertilizer use,

$$\begin{aligned} \text{Min}E_1(x) = & 0.9x_1 + 0.05x_2 + 0.05x_3 + 3.14x_4 \\ & + 2.35x_5 + 3.53x_6 + 2.89x_7 + 0.1x_8 \\ & + 0x_9 + 0x_{10} \end{aligned} \tag{19}$$

For fertilizer need of each crop,

$$\begin{aligned} \text{Min}E_1(x) = & 0.9x_1 + 0.05x_2 + 0.05x_3 + 1.75x_4 \\ & + 1.31x_5 + 1.97x_6 + 1.62x_7 + 0.1x_8 \\ & + 0x_9 + 0x_{10} \end{aligned} \tag{20}$$

Table 5 Unit values for land use types for the Namazgah reservoir

	Rural residential area (X1)	Forest (X2)	Wood land (X3)	Wheat–barley cultivation (X4)	Nut cultivation (X5)	Corn cultivation (X6)	Fruit and vegetables cultivation (X7)	Non-planted land (X8)	Water body (X9)	FSOIZ (X10)
TP ^a (kg ha ⁻¹ year ⁻¹)	0.9	0.05	0.05	3.14	2.35	3.53	2.89	0.1	0	0
TP ^b (kg ha ⁻¹ year ⁻¹)	0.9	0.05	0.05	1.75	1.31	1.97	1.62	0.1	0	0
IC ^c (USD ha ⁻¹ year ⁻¹)	15,709	82	0	118	381	77.25	5,109.27	0	2,105,209	1,232,476

^a Current fertilizer use

^b Fertilizer need for each crop type

^c The economic income was calculated in USD, and it was accepted that 1 USD equals to 1.94 Turkish Lira (TL). Inflation was ignored

Table 6 The maximum and minimum TP values according to the current fertilizer use

E1 min kg TP year ⁻¹	E2 val Million USD year ⁻¹	X1 (ha)	X2 (ha)	X3 (ha)	X4 (ha)	X5 (ha)	X6 (ha)	X7 (ha)	X8 (ha)	X9 (ha)	X10 (ha)
11,703.42	323.71	215.73	2,150.00	2,388.39	0	4,801.00	0	0	0	321.48	203.40
E1 max kg TP year ⁻¹	E2 val Million USD year ⁻¹	X1 (ha)	X2 (ha)	X3 (ha)	X4 (ha)	X5 (ha)	X6 (ha)	X7 (ha)	X8 (ha)	X9 (ha)	X10 (ha)
13,854.70	324.22	215.73	2,150.00	1,453.00	0	5,736.00	0	0	0	321.48	203.40

2. Total income

$$\begin{aligned} \text{Max}E_2(x) = & 15,709x_1 + 82x_2 + 0x_3 + 118x_4 + 381x_5 \\ & + 77x_6 + 5,109.2x_7 + 0x_8 + 215,209x_9 \\ & + 12,322,476x_{10} \end{aligned} \tag{21}$$

$$\begin{aligned} & 0.9x_1 + 0.05x_2 + 0.05x_3 + 1.75x_4 + 1.31x_5 + 1.97x_6 \\ & + 1.62x_7 + 0.1x_8 + 0x_9 + 0x_{10} \leq 13,855 \end{aligned} \tag{32}$$

11. Non-negativity $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10} \geq 0$ (33)

Constraints

1. Land availability : $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} = 10,089$ (22)

2. Min. residential area : $x_1 \geq 215.3$ (23)

3. Max. residential area : $x_1 \leq 656.6$ (24)

4. Forest area : $x_2 = 2,150$ (25)

5. Woodland : $x_3 \geq 1,138$ (26)

6. Max agricultural area : $x_4 + x_5 + x_6 + x_7 + x_8 \leq 6,052$ (27)

7. Min agricultural area : $x_4 + x_5 + x_6 + x_7 \geq 4,801$ (28)

8. Water body : $x_9 = 321.28$ (29)

9. FSOIZ area $x_{10} \leq 203.4$ (30)

10. TP assimilative capacity : $0.9x_1 + 0.05x_2 + 0.05x_3 + 3.14x_4 + 2.35x_5 + 3.53x_6 + 2.89x_7 + 0.1x_8 + 0x_9 + 0x_{10} \leq 13855$ (31)

Results

The results of the optimization of each individual single objective are given in Tables 6, 7, and 8. Table 6 shows that the min value of TP load ($E1_{\min} = 11,703.42$ kg TP year⁻¹) according to the current fertilizer use is very close to the assimilation capacity of dam reservoir, indicating that agriculture with this amount of fertilizer is a threat to the reservoir. Obviously, this situation is not acceptable. There are two ways to prevent the unavoidable consequences. The first would be to exclude the agricultural activities from the system or secondly unnecessary use of fertilizers can be prevented. Since the establishment of FSOIZ was planned in this area, agricultural activities cannot be excluded from the system. Therefore, both the game theory and the fuzzy programming applications were rerun considering that only the amount of fertilizer needed by each crop would be provided.

According to Table 7, the minimum TP load was achieved when nuts were cultivated on all the current cultivated agricultural lands, and the maximum TP load was achieved when corn was cultivated to all the agricultural lands.

According to Table 8, the minimum IC value was obtained when corn was cultivated to the whole agricultural land, and FSOIZ was not a part of the system. To obtain the maximum

Table 7 The max and min TP values according to the need of fertilizer in each crop

E1 min kg TP year ⁻¹	E2 val Million USD year ⁻¹	X1 (ha)	X2 (ha)	X3 (ha)	X4 (ha)	X5 (ha)	X6 (ha)	X7 (ha)	X8 (ha)	X9 (ha)	X10 (ha)
6,710.38	323.71	215.73	2,150.00	2,388.39	0	4,801.00	0	0	0	321.48	203.40
E1 max kg TP year ⁻¹	E2 val Million USD year ⁻¹	X1 (ha)	X2 (ha)	X3 (ha)	X4 (ha)	X5 (ha)	X6 (ha)	X7 (ha)	X8 (ha)	X9 (ha)	X10 (ha)
12,463.50	74.74	418.52	2,150.00	1,138.00	0	0	6,052.00	0	0	321.48	0

Table 8 The maximum and minimum IC values

E1 val kg TP year ⁻¹	E2 min Million USD year ⁻¹	X1 (ha)	X2 (ha)	X3 (ha)	X4 (ha)	X5 (ha)	X6 (ha)	X7 (ha)	X8 (ha)	X9 (ha)	X10 (ha)
9,951.76	71.64	215.73	2,150.00	1,340.79	0	0	4,801.00	0	1,251.00	321.48	0
E1 val kg TP year ⁻¹	E2 max Million USD year ⁻¹	X1 (ha)	X2 (ha)	X3 (ha)	X4 (ha)	X5 (ha)	X6 (ha)	X7 (ha)	X8 (ha)	X9 (ha)	X10 (ha)
9,844.36	357.73	656.62	2,150.00	1,138.00	0	0	0	5,610.50	0	321.48	203.40

IC value, the residential area was increased from 215.73 to 656.62 ha, vegetables–fruits were cultivated in the whole agricultural land, and FSOIZ was accepted as a part of the system.

Results of game theory model

For the model established for this basin, the algorithm was rerun several times, and the *n* coefficient was determined as 149 that provides the most reasonable concession value, and the first game was started by giving concessions. The initial goal for player 1 was to obtain a TP load of 6,748.99 kg TP year⁻¹ and an income of 324.22 million USD year⁻¹. Similarly, the initial goal for player 2 was to obtain an income of 355.67 million USD year⁻¹ and a TP load of 9,254.34 kg TP year⁻¹, as shown in Table 9. It can be deduced from these values that the initial goals of players could not be achieved. Therefore, both players were not satisfied from the results and continued bargaining rounds. During these rounds, the players increased their compromises and lowered their goals. Player 1 reduced their environmental expectation and increased the TP load from 6,748.99 to 6,903.44 kg TP year⁻¹, and player 2 lowered their income expectation from 355.67 million to 347.93 million USD year⁻¹, as seen in Table 9. The bargaining rounds continued until the 13th round. After this round, for player 1, the final values were TP_{final}=7,212.33 kg TP year⁻¹ and IC_{final}=332.47 million USD year⁻¹, whereas for player 2, TP_{final}=7,208.21 kg TP year⁻¹ and IC_{final}=332.47 million USD year⁻¹. These results satisfied both players, and the Nash

equilibrium was reached (Eqs. 11 and 12). The results of four bargaining rounds are shown in Fig. 5.

Table 9 also shows that wheat–barley cultivation land (X4), corn cultivation land (X6), and non-planted land (X8) were removed from the system due to the high TP load and low income values. The player’s initial goals, rural residential area (X1), woodlands (x3), nut cultivation (X5), and vegetables–fruit cultivation (X7) values were quite different from each other; however, the difference decreased after each bargaining round. The value for FSOIZ (X10) land was unchanged during the bargaining rounds, due to high income and low TP loading values.

The results of fuzzy programming approach

To apply fuzzy programming approach, we first determined min and max values of TP and IC. By using these values shown in Tables 7 and 8, membership functions were constructed as follows:

$$\mu(\text{TP}) = \frac{12,463.50 - E_1}{12,463.50 - 6,710.38}$$

$$\mu(\text{IC}) = \frac{E_2 - 71.64 \times 10^6}{(357.73 - 71.64) \times 10^6}$$

By using these membership functions, the model of the fuzzy programming approach for our case study (Eq. 16) is

Table 9 Players’ strategies and bargaining process

Rounds	E1 kg TP year ⁻¹	E2 Million USD year ⁻¹	X1 (ha)	X2 (ha)	X3 (ha)	X4 (ha)	X5 (ha)	X6 (ha)	X7 (ha)	X8 (ha)	X9 (ha)	X10 (ha)
1st round	6,748.99	324.22	261.15	2,150.00	2,342.96	0	4,801.00	0	0	0	321.48	203.40
	9,254.34	355.67	656.62	2,150.00	1,513.81	0	0	0	5,234.68	0	321.48	203.40
5th round	6,903.44	327.31	442.85	2,150.00	2,161.26	0	4,801.00	0	0	0	321.48	203.40
	8,215.21	347.93	656.62	2,150.00	1,947.50	0	1,155.61	0	3,645.38	0	321.48	203.40
10th round	7,096.50	330.92	656.62	2,150.00	1,947.50	0	4,764.35	0	36.64	0	321.48	203.40
	7,585.84	338.14	656.62	2,150.00	1,947.50	0	3,185.84	0	1,615.15	0	321.48	203.40
13th round	7,212.33	332.47	656.62	2,150.00	1,947.50	0	4,390.69	0	410.30	0	321.48	203.40
	7,208.21	332.47	656.62	2,150.00	1,947.50	0	4,403.98	0	397.01	0	321.48	203.40

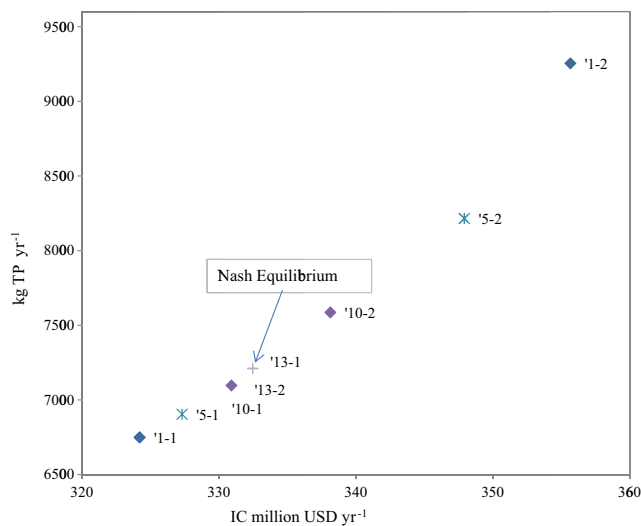


Fig. 5 Results of game theory approach

constructed. The results of fuzzy programming approach are shown in Table 10. The TP load and income values were determined as 7,210 kg TP year⁻¹ and 332.47 million USD year⁻¹. The decision variables X3, X4, and X6 were removed from the system. Rural residential area (X1) value was 656.62 ha, nut cultivation land (X5) value was 4,395.95 ha, and vegetable–fruit cultivation land (X7) value was 405.04 ha. Satisfaction coefficient was obtained to be 0.91.

Conclusions

This study dealt with balancing economic and environmental impacts in the Namazgah reservoir using game theory and fuzzy programming approaches. The main goals were to maximize economic benefits of land use and to protect water quality of reservoir and land resources. The overall results showed that the results of fuzzy programming approach were very close to the results of the game theory model, as can be seen from Tables 9 and 10. The results obtained indicated that the amount of fertilizer used in the current situation presents a danger to the reservoir and the unnecessary fertilizer use should be prevented. Thus, farmers should be informed about the use of fertilizers, and the necessary control measures should be taken.

There are several problems in our country from the point of agricultural activities. For example, most of the agricultural lands are usually fragmented into small portions and, therefore, small-scale land operation is mostly carried out. In addition to these, low production levels for the market in

rural areas and low education levels among the farmers are in question. Due to inadequacy of investigation of alternative agricultural products for the market, agricultural policies, and instability in product prices (TUBITAK 2003), the producers, with the influence of habit, tend to cultivate cereal products mainly, as market is generally guaranteed by the government. By this way, although the producers would not get a profit as they wish, the risks are eliminated partially. The main reason of producing cereal in the basin studied can be linked to these problems. However, as the results indicated, to produce nuts instead of wheat and corn would be more beneficial for both the producers (player 2) and the environment (player 1), as the yield factors are low for these cereal products, and additionally, nut production is both economical and leads to low TP values for the receiving water media.

Wheat and corn were the first decision variables removed from the model due to generating high TP loads and low income values. To change this situation, the awareness of the farmers should be increased concerning proper planting, fertilizing, spraying, and irrigation. Likewise, the farmers should be trained to use modern techniques which may then increase the economic returns. In addition, the producers could be encouraged and supported to shift to lower fertilizer and manure application rates, by which fertilizer and manure usage would be minimized, and the producers might have the chance to sell their products at higher price.

The results did not show a remarkable change in the current situation of fruit and vegetable production, of which the farmers meet only their own needs and do not expect a serious economic income. The main reason for this situation could be relatively high cost of the initial investment for vegetables and fruits compared to grain products, more labor force, lack of market warranty, and unsuitable soil structure. The decision makers could change this situation by developing agricultural policies. There are, in fact, a number of different ways to protect precious water resources and to increase economic returns, such as opening ways for small businesses to grow by combining parcels of land, supporting lower fertilizer and manure application rates, promoting greenhouse applications, which climate change impact can be reduced, training farmers on suitable alternative product selection according to soil structure and climatic conditions, and lastly providing necessary support in this regard.

Another result obtained was to increase the area of livestock activities within the rural residential areas. To achieve this, the

Table 10 Results of fuzzy programming

	E1 kg TP year ⁻¹	E2 million USD year ⁻¹	X1 (ha)	X2 (ha)	X3 (ha)	X4 (ha)	X5 (ha)	X6 (ha)	X7 (ha)	X8 (ha)	X9 (ha)	X10 (ha)
0.91	7,210.70	332.47	656.62	2,150.00	1,947.50	0	4,395.95	0	405.04	0	321.48	203.40

owners of these small enterprises, where animal farming is a small-scale traditional business to meet the family's cost and expenditures, should be guided and promoted to shift to larger scale animal farming. Additionally, the decision makers should set and implement appropriate policies on some issues related to animal farming such as merging small-scale businesses, supplying credit facilities to meet the initial investment costs, and providing necessary technical and educational support on safe storage and usage of manure as a fertilizer without adversely affecting water resources. In addition to these activities, necessary initiatives should be instituted between the farmers and the industries which will take place in the FSOIZ. Thus, while farmers would found a market for their products, raw material needs for the factories would be met.

One of the other results of the model runs was to increase woodlands slightly compared to the current situation. Afforestation should be carried out on the riverside of the creeks and streams in the basin and in the expropriated areas within the strict preservation zone of the dam as well as on the lands which are not cultivated for various reasons. These afforested areas should be open for public use including camping areas, walking courses, hiking trails, and recreational areas, so that at least partial economic returns can be achieved.

Decisions such as to build a dam on a stream or to convert a region to an industrial zone are usually taken by the decision makers without consulting the people living in the region, most of the time. Therefore, the authors believe that it is quite important to determine the point where these two main economic variables would bring the economy of the region to and to see the approach of the environmental variables. In case the wastewater treatment plant is operated continuously, and necessary measures are taken for point and non-point loads, the FSOIZ can be accepted by the system due to high income expectations.

The authors believe that the results obtained in this study will help decision makers to identify possible problems of the watershed and will give an idea about the solutions of these problems. Both programming approaches were applied successfully for the first time in watershed management in Turkey, and it can be said that more applications can be executed in the other watersheds.

References

- Abaci O, Papanicolaou AN (2007) Identifying the equilibrium conditions for an agricultural Iowa catchment using the Water Erosion Prediction Project (WEPP) model. *Proceeding of ASCE World Environmental and Water Resources Congress: Restoring Our Natural Habitat*, Tampa, Florida [http://dx.doi.org/10.1061/40927\(243\)617](http://dx.doi.org/10.1061/40927(243)617)
- Agricultural Statistics (2001) <http://www.nationmaster.com/country/turkey/agr-agriculture>
- Andreadakis A, Gavalakis E, Kaliakatsos L, Noutsopoulos C, Tzimas A (2007) The implementation of the Water Framework Directive (WFD) at the river basin of Anthemountas with emphasis on the pressures and impacts analysis. *Desalination* 210(1–3):1–15
- Chen CW, Dean JD, Gherini SA, Goldstein RA (1982) Acid rain model hydrologic module. *J. Environ. Eng. ASCE* 108(E3):455–472 (The doi for this paper is not reachable)
- Crawford NH, Linsley RK (1966) Digital simulation in hydrology: Stanford Watershed Model IV. Technical report No. 39, Department of Civil Engineering, Stanford University, 210.
- Dahl S, Kurtar B (1993) Environmental situation, working paper, no. 21, Omerli and Elmali Environmental Protection Project—Feasibility Report, Omerli and Elmali Joint Venture 1.1–5.10, Turkey
- Davila E, Chang NB, Diwakaruni S (2005) Landfill space consumption dynamics in the lower Rio Grande valley by grey integer programming-based games. *J. Environ. Manage.* 75:353–365 <http://dx.doi.org/10.1016/j.jenvman.2004.11.015>
- Draper AJ, Jenkins MW, Kirby KW, Lund JR, Howitt RE (2003) Economic-engineering optimization for California water management. *J Water Res Plan Manag ASCE* 129(3):155–164. doi:10.1061/(ASCE)0733-9496(2003)129:3(155)
- Duckstein L, Opricovic S (1980) Multiobjective optimization in river basin development. *Water Resour Res* 16(1):14–20. doi:10.1029/WR016i001p00014
- East Marmara Development Agency (2011) The food specialized organized industrial zone report. http://www.dogumarmarabolgeplani.gov.tr/pdfs/2_osb_93_Kand%C4%B1raGIOSBgorusu.pdf
- Erturk A, Gurel M, Ekdal A, Tavsan C, Ugurluoğlu A, Seker DZ, Tanik A et al (2010) Water quality assessment and meta model development in Melen watershed—Turkey. *J Environ Manag* 91(7):1526–1545. doi:10.1016/j.jenvman.2010.02.021
- Esen E, Uslu O (2008) Assessment of the effects of agricultural practices on non-point source pollution for a coastal watershed: a case study Nif Watershed, Turkey. *Ocean Coastal Manag* 51(8–9):601–611. doi:10.1016/j.ocecoaman.2008.06.012
- Gershon M, Duckstein L (1983) Multi objective approaches to river basin planning. *J Water Res Plan Manag* 109(1):13–28. doi:10.1029/WR018i002p00193
- Gibbons R (1997) An introduction to applicable game theory. *J Econ Perspect* 11:127–149. doi:10.1257/jep.11.1.127
- Habarth ML, Barkdoll B (2009) Hydrologic modeling and flood frequency analysis of the Sonora River Watershed in Sonora, Northwest Mexico. *Proceeding of World Environmental and Water Resources Congress: Great Rivers*. Kansas City, Missouri, [http://dx.doi.org/10.1061/41036\(342\)644](http://dx.doi.org/10.1061/41036(342)644)
- Hadjikakou M, Whitehead PG, Jin L, Futter M, Hadjinicolaou P, Shahgedanova M (2011) Modelling nitrogen in the Yeşilirmak River catchment in Northern Turkey: impacts of future climate and environmental change and implications for nutrient management. *Sci Total Environ* 409(12):2404–2418. doi:10.1016/j.scitotenv.2011.02.038
- Jenkins MW, Lund JR, Howitt RE, Draper AJ, Msangi SM, Tanaka SK, Ritzema RS, Marques GF (2004) Optimization of California's water system: results and insights. *J Water Resour Plan Manag* 130(4): 271–280. doi:10.1061/(ASCE)0733-9496(2004)130:4(271)
- Kacar B, Katkat V (1997) Phosphorous in agriculture. Bursa Chamber of Commerce Publications, Bursa, in Turkish
- Karpuzcu M, Wendland F, Kocal M, Tetzlaff B, Pekdeger A, Oncel S, Voigt H, et al. (2006) Preliminary investigation on integrated modelling of nutrient loads in catchment areas. A case study: the Porsuk Reservoir catchment. 10th Int. Specialised Conference on Diffuse Pollution and Sustainable Basin Management, Istanbul
- Lamy F, Bolte J, Santelmann M, Smith C (2002) Development and evaluation of multiple-objective decision-making methods for watershed management planning. *J Am Water Resour Assoc* 38:17–529. doi:10.1111/j.1752-1688.2002.tb04334.x

- Lee CS (2012) Multi-objective game-theory models for conflict analysis in reservoir watershed management. *Chemosphere* 87(6):608–613. doi:10.1016/j.chemosphere.2012.01.014
- Lee CS, Chang SP (2005) Interactive fuzzy optimization for an economic and environmental balance in a river system. *Water Res* 39(1):221–231. doi:10.1016/j.watres.2004.09.013
- Lund JR, Ferreira I (1996) Operating rule optimization for Missouri River reservoir system. *J Water Res Plan Manag* 122(4):287–295. doi:10.1061/(ASCE)0733-9496(1996)122:4(287)
- Lund JR, Palmer RN (1997) Water resource system modeling for conflict resolution. *Water Resour.* 3(108):70–82 (Water Resources Update was established in 1964. Current title is named as the Journal of Contemporary Water Resources Research and Education. Therefore the doi for this paper is not reachable.)
- Maneta MP, Torres MO, Wallender WW, Vosti S, Howitt R, Rodrigues L, Bassoi LH, Panday S (2009) A spatially distributed hydroeconomic model to assess the effects of drought on land use, farm profits, and agricultural employment. *Water Resour Res* 45:1–19. doi:10.1029/2008WR007534
- Ministry of Environment and Urbanization (2009) Food specialized organized industrial zone environmental impact assessment report. www2.cedgm.gov.tr/cedsureci/ced_basvuru_dosyasi/350_ptd.pdf
- Ministry of Environment and Urbanization (2011) Namazgah reservoir environmental impact assessment report. www.cedgm.gov.tr/CED/Files/cedsureci/nihai_edilen.../723_nihai.pdf
- Ministry of Forestry and Water Affairs (2012) Surface water quality management regulation. <http://www.resmigazete.gov.tr/main.aspx?home=http://www.resmigazete.gov.tr/eskiler/2012/11/20121130.htm&main=http://www.resmigazete.gov.tr/eskiler/2012/11/20121130.htm>
- Mirchi A, Watkins DJr, Madani K (2009) Modelling for watershed planning, management, and decision making. In: Vaughn JC (ed) *Watersheds: management, restoration and environmental*. Nova Science Publishers, Inc, pp 1–25
- Murat H (2011) Economic analysis of dairy cattle establishments under the Cattle Breeders Association in Aegean and Central Anatolian regions. Dissertation, Ankara University
- OEJV (1993) Omerli-Elmalı Joint Venture/Protection Omerli and Elmalı Environmental Protection Project, Feasibility Study, Progress Report, Istanbul Water and Sewerage Administration, Turkey (*in Turkish*)
- Osborne M, Rubinstein A (1994) *A course of game theory*. MIT Press, Cambridge, MA
- Ozturk I, Tanik A, Cokgor E, Gurel M, Mantas E, Insel G, Ozabalı A (2007a) Final report of the watershed protection action plan, greater Istanbul water supply Melen system 2nd stage project of big Melen river basin integrated protection and water management master plan, Istanbul Technical University, Department of Environmental Engineering, Istanbul, Turkey (*in Turkish*)
- Ozturk I, Tanik A, Seker DZ, Alp K, Gurel M, Erturk A, Ekdal A, Tavsan C, Zorlutuna Y (2007b) Water quality final feasibility report, greater Istanbul water supply Melen system 2nd stage project of big Melen river basin integrated protection and water management master plan. Istanbul Technical University, Department of Environmental Engineering, Istanbul (*in Turkish*)
- Parrachino I, Zara S, Patrone F (2006) Cooperative game theory and its application to natural, environmental, and water resource. World Bank Policy Research Working Paper, Washington, DC, p 4072
- Rogers P (1969) A game theory approach to the problems of international river basins. *Water Resour Res* 5(4):749–760. doi:10.1029/WR005i004p00749
- Saatci Y, Ipek U, Tanyildizi S, Cinarci B (1999) Research on determining trophic levels of Keban Dam Lake in Uluova Region. *Water Pollut Cont* 9(3):41–49, *in Turkish*
- Singh VP, Woolhiser DA (2002) Mathematical modeling of watershed hydrology. *J Hydrol Eng* 7(4):270–292. doi:10.1061/(ASCE)1084-0699(2002)7:4(270)
- State Hydraulic Works (2007) VII Regional Directorate of Planning Branch Report, http://www.emo.org.tr/ekler/a6d3cc166fbfbf0_ek.pdf
- TUBITAK (2003) Final report on agriculture and food (*in Turkish*) www.tubitak.gov.tr/tubitak_content_files/.../tarimgida_son_sorum.pdf
- Turoğlu H (2005) Floods occurred in Bartın, flood mitigation and prevention tips. Turkey Quaternary Symposium (*in Turkish*) [http://www.irfanakar.com/turkish/pdf2/ua/Makaleler/Dogal_Afetler/1%20\(12\).pdf](http://www.irfanakar.com/turkish/pdf2/ua/Makaleler/Dogal_Afetler/1%20(12).pdf)
- Vollenweider RA (1976) Advances in defining critical loading levels for phosphorus in lake eutrophication. CCIW, Burlington, p 243
- Von Neumann J, Morgenstern O (1944) *Theory of games and economic behavior*. Princeton University Press, Princeton
- Wang JH, Lu XG, Jiang M, Li XY, Tian JH (2009) Fuzzy synthetic evaluation of wetland soil quality degradation: a case study on the Sanjiang Plain, Northeast China. *Pedosphere* 19(6):756–764. doi:10.1016/S1002-0160(09)60171-5
- Wen CG, Lee CS (1998) A neural network approach to multi-objective optimization for water quality management in a river basin. *Water Resour Res* 34:427–436. doi:10.1029/97WR02943
- Zimmermann HJ (1991) *Fuzzy set theory and its applications*, revised edition. Kluwer Academic Publishers, Boston/Dordrecht/London