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Optimal land-use allocation using MCDM and SWAT for the Hablehroud Watershed, Iran

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ABSTRACT

The watershed, a dynamic and integrated social, economic, and biological system, plays an important role in the growth and development of the economy. Watersheds as a basis to support natural life and human activities have been heavily damaged over the past few centuries. One of the major causes of which is the inappropriate land-use allocation. Studies on land-use allocation mostly investigate optimization methods apart from each other but combining different approaches and comparing outcomes of different methods seems to be more helpful, especially for the decision-makers in a watershed. Hablehroud watershed as an important agricultural production region in Iran has been facing different ecological and economic problems during recent decades. Therefore, the current study aimed to determine the optimal land-use allocation according to the economic, social, and environmental criteria in the Hablehroud watershed using multi-criteria decision-making (MCDM) method. The optimal land-use solutions were obtained using the weighted goal programming (WGP), lexicographic goal programming (LGP), and compromise programming (CP) methods. The results indicated that after the optimization, in all the scenarios (economic, neutral and environmental), the average values of the environmental criteria decreased 66 % in WGP, 65 % in LGP and 66.6 % in CP and the social criterion increased 62 % in WGP, 82 % in LGP, and 46.3 % in CP. The values of the economic criteria (profit) increased 2% in WGP, 21 % in LGP and 6% (on average) in CP, only in the economic scenario. However, the economic scenarios showed a better results in all of the methods, based on which the recommendations were made to improve watershed management policies based on the optimal land-use patterns.

1. Introduction

A watershed is a logical unit for land-use planning and sustainable management of natural resources and the environment (Molle, 2017). Watersheds around the world have been regularly refurbished over the centuries and recently faced slow but severe erosion and decomposition in recent decades (Gebretsadik, 2014; McDonald et al., 2016; Molle et al., 2010; Moravcová et al., 2016; Shen et al., 2017). In Iran, most of the watersheds are today facing these problems in different ways. Over 2 billion tons of soil from 125 million hectares of the country area have been destroyed annually by water and wind erosion. About 1.5 million tons are productive arable soil from the erosion in the watersheds. The average soil erosion is about 25–30 tons per hectare per year and the average sediment yield behind the dams is about 10 tons per hectare. Also, the rangelands are destroyed by 130,000 ha annually and the forests lose 48,000 ha each year (Athari et al., 2017; Jahangir et al., 2019; Mosavi et al., 2020; Akbari et al., 2020). Therefore, along with social and economic aspects, it is necessary to responsibly conserve water and soil resources within a resource management plan (Sadeghi et al., 2009; Wang et al., 2016; Alipour et al., 2020).

One of the main factors disrupting the balance of ecosystems is the inappropriate changes of land covers and land usage to introduce activities beyond the natural potential of the lands (Benini et al., 2010; Salman Mahini et al., 2014). The proper land-use composition is one of the important factors for soil and water conservation, especially in watersheds. This enables watershed managers to choose the best among different land-use combinations. Therefore, the residents' income would be raised and the pollution of water and soil resources besides erosion and sedimentation would be decreased simultaneously (Adhami et al., 2018; Emirhüseyinoğlu and Ryan, 2020; Paroissien et al., 2015).

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Different technical, physical, social, and ecological dimensions in the watershed planning process and the complex interactions between these components complicates the management of water and soil resources. In addition, different aspects of agricultural activities and their interactions with the environment, as well as the conflicts of interests among different decision makers necessitate the use of multi-criteria decision-making methods on how to allocate lands among these activities (Huang et al., 2011). Multi-criteria decision-making (MCDM) analysis is the study of methods by which multiple conflicting criteria can be correctly applied in the planning process (Ballestero and Romero, 2013). These methods are generally divided into two categories: discrete multi-criteria and continuous multi-criteria. The methods are called discrete or multi-attribute when a limited number of alternatives are considered and the set of solutions can be counted and are called continuous or multi-objective when the values of the alternatives are calculated in final solution (Zavadskas et al., 2019). In addition, measuring the environmental criteria in the watershed, due to the extent of the watersheds and the nature of the criteria, makes it necessary to use simulation methods. The soil and water assessment tool (SWAT) (Neitsch et al., 2011) is one of the useful models to estimate the amounts of the environmental criteria in the watersheds. Applying the model in a geographic information system (GIS) environment, SWAT simulates hydrological processes, soil erosion, water quality, land-use/cover change and climate change impacts. It is also a powerful tool in the environmental studies and planning (Francesconi et al., 2016; Fukunaga et al., 2015; Zhang et al., 2013).

Land-use optimization is a way towards sustainable watershed management. Considering the conflict between the economic and environmental objectives, it provides the best land-use composition to achieve the optimum level of environmental protection and economic growth. A general review of studies on the land-use optimization allocation suggests two major categories: non-spatial optimization (Moradi and Limaei, 2018; Ou et al., 2017; Rao et al., 2018; Sadeghi et al., 2009; Wu et al., 2018; Zhang et al., 2014; Zhou et al., 2015) and spatial optimization (Chen et al., 2015; Hao et al., 2017; Li and Ma, 2018; Pilehforooshha et al., 2014; Shaygan et al., 2014; Strauch et al., 2019; Yao et al., 2018; Zhang et al., 2012). Spatial optimization is based on the integration of GIS with spatial allocation of lands. In both of the categories, multi-criterion decision- making methods are widely used for different land-use planning issues. Multi-objective decision-making methods (MODM) as one of the main branches of MCDM, are mostly used in studies related to land-use allocation or land-use plan designs (García et al., 2017; Li and Parrott, 2016; Ma and Zhao, 2015; Qi and Altinakar, 2013; Ramezanian and Hajipour, 2020), whereas multi-attribute decision-making methods (MADM) as the other branch of MCDM are mostly used in studies related to land suitability analysis, site selection, etc. (Antón et al., 2016; Li and Chen, 2020; Mosadeghi et al., 2015; Nguyen et al., 2017; Yu et al., 2018). A closer look to the literature on land use studies reveals that, most of them have investigated the approaches and methods apart from each other. Every approach and method has its own advantages and disadvantages in finding a suitable final outcome (Haddad and Sanders, 2018). Combinations of different approaches could compensate for the drawbacks of one method and add useful features of another (Kaim et al., 2018). In addition, comparing different methods according to the obtained results could help decision makers to explore, study and evaluate different possibilities and finally choose more appropriate solutions. However, it seems to be a lack of studies on combining different approaches and comparing outcomes of different methods on land-use allocation studies, particularly, for the studies conducted in the Hablehroud watershed.

With the collaboration of the government of Iran, FAO, and the UNDP, Hablehroud watershed was selected as a pilot area to implement a project about a sustainable management of land and water resources (SMLWR) since 1997. In addition, this watershed is an important agricultural production hub to supply food especially in Tehran. Ecological, economic and social characteristics of the Hablehroud watershed and the implementation of such projects in the area necessitates further studies, to evaluate the achievements or to provide more solutions to the problems in the area. On the one hand, poor natural resources conditions in the watershed requires conservation, restoration and development measures. On the other hand, half of the villages abandoned due to the socio-economic problems, requires solutions towards appropriate watershed management practices. (Kazemi et al., 2006). Therefore, this study aims to develop optimal land-use allocations via the multi-criterion decision-making methods and the soil and water assessment tool model in Hablehroud watershed.

2. Materials and methods

2.1. Soil and water assessment tool

Soil and water assessment tool (SWAT) is a comprehensive model used to simulate the quality and quantity of surface and ground water and predict the environmental effect of land use, land management practices, and climate change developed by the USDA Agricultural Research Service (Neitsch et al., 2011). Performed in GIS environment, this model simulates hydrological processes including soil erosion, sediment and chemical yields which empower this tool in the environmental studies and planning. The smallest unit of SWAT is the Hydrologic Response Unit (HRU), derived according to the land use, soil type and land slope combinations. Parameters related to soil water, surface runoff, sediment and chemical yields are first calculated for each HRU and then for each sub-watershed and the entire watershed.

Due to the extent of the watershed and its topographic features, and following Salman Mahini et al. (2014), the watershed was divided into northern and southern parts. Using the digital elevation map (DEM) and the waterway networks, the watershed was divided into 70 sub-watersheds. Subsequently, 682 HRUs were formed by overlaying the land use, soil and slope maps. Rainfall and daily temperature data were then inserted into the model. The surface runoff volume was estimated via a modified Soil Conservation Service-Curve Number (SCS CN) method. SWAT determines a SCS CN for each simulated day based on antecedent soil moisture in conjunction with daily soil moisture values determined by the model. This daily SCS CN is then used to determine a theoretical storage capacity (S) of the watershed for each day. This storage (S) is then used to calculate runoff volume (Q_s) via

$$Q_s = \frac{(R_{day} - I_a)^2}{R_{day} - I_a + S} \tag{1}$$

Where Q_s is the depth of the surface runoff. S is the watershed storage, R_{day} the precipitation, and I_a the initial abstraction which is assumed to be equal to 0.2S. All parameters are values for the day in millimeter (Tasdighi et al., 2018).

The amount of soil erosion and sediment yield were also separately estimated for each HRU and on a daily time basis using the Modified Universal Soil lost Equation (MUSLE) (Williams, 1975):

$$sed = 11.8(Q_s\, q_p\, A)^{0.56}\, K\, C\, P\, LS\, CFRG \tag{2}$$

Where sed is sediment yield (t/day); Q_s is daily runoff volume (mm); q_p is runoff peak discharge (m^3/s); A is HRU area (ha); C, P, K, and LS are dimensionless factors accounting for HRU crop cover, soil protection, soil erodibility, and topography and $CRFG$ is a dimensionless factor to account for coarse fragment cover (Vigiak et al., 2015).

2.2. Multi-criteria decision method

2.2.1. MADM

2.2.1.1. Analytic hierarchy process (AHP). The analytic hierarchy process (AHP) is one of the efficient multi-attribute decision-making methods (Saaty, 1980). It is based on the pairwise comparisons that facilitate the judgments and calculations and provide decision makers with different scenarios. The AHP model involves several steps (Jothibasu and Anbazhagan, 2016): 1) Identify and define the unstructured problem and objectives of the study; 2) determine the detailed criteria and alternatives and rearrange them into a hierarchical sequence; 3) apply pair-wise comparisons to prepare comparison matrices using a preference scale of 1–9; 4) use the eigenvalue technique to determine the relative weights of the decision factors; 5) compute the consistency index of the matrices; and 6) obtain an overall weighting of the alternatives. To capture the decision-makers judgments correctly, AHP uses the principal eigenvalue and the consistency index (CI). For computing the CI, the following formula is applied:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3}$$

Where, λ_{max} is the largest eigenvalue of the pairwise comparison matrix and n is the number of competing options. The Consistency Ratio (CR) is also computed as follows:

$$CR = \frac{CI}{RI} \tag{4}$$

Where RI represents the random consistency index which is dependent on n matrix size given by Saaty (1980). For the comparisons to be consistent, the CR must be less than 0.1. In this study, this technique was used merely for building scenarios on criteria. First, an expert questionnaire was designed and data were collected from the experts in the SMLWR project to determine the weights of the criteria. Then, three economic, neutral and environmental scenarios were developed. Finally, the effects of each scenario on the land allocation was investigated via MODM models.

2.2.2. MODM

In multi-objective decision-making models, finding the best optimal alternative is based on setting the model constraints, different goals and the desired values of the decision maker(s) for these goals. Several goals with different scales are simultaneously considered for optimization. In this study, following the procedure proposed by Kaim et al. (2018) to select an appropriate approach for land-use allocation problems, three multi-objective models were considered for the optimal land-use allocation: weighted goal programming (WGP), lexicographic goal programming (LGP), and compromise programming (CP). These methods which were selected due to the capability of modeling the problem based on the aims of the study and the problem's characteristics, are widely used in decision-making analysis (Castro et al., 2018; Cisneros et al., 2011; Colapinto et al., 2019; Freitas et al., 2019). Comparing the obtained results can help decision makers to select more appropriate solutions.

2.2.2.1. Weighted goal programming (WGP). The general form of the model is as follows (Charnes and Cooper, 1977; Ignizio, 1976; Lee, 1972):

$$\min_{x_i, f_j, n_j, p_j} \left(\sum_j \frac{(n_j.\, w_j + p_j.\, w_j)}{rb_j} \right) \tag{5}$$

$$f_j + n_j - p_j = gb_j \tag{6}$$

$$f_j = \sum_i (a_{ij}.\, x_i) \tag{7}$$

$$\sum_i (a_{ik}.\, x_i)(\leq or \geq or = c_k) \tag{8}$$

$$x_i,\, n_j,\, p_j \geq 0 \tag{9}$$

Where x_i represents the decision variable and gb_j is the target level of the j-goals. The variable f_j as a function of the decision variables is the level of achievement for each criterion and p_j and n_j are the positive and negative deviations from these levels. The a_{ij} is a technical coefficient matrix showing the linear relation between the decision variables and the criteria. The w_j represents the relative importance of the goals given by the decision maker. The c_k is the right hand side of the constraints. In Eq. (5), the positive and negative deviations are normalized by dividing by rb_j which often equals gb_j, getting independence on units.

2.2.2.2. Lexicographic goal programming (LGP). In this method, first a group of higher priority goals is satisfied, then the remaining goals are addressed in a defined priority order (Ballestero and Romero, 2013; Romero, 1991). The objective function is as follows and the constraints are the same as Eqs. (6)–(9):

$$\underset{x_i, f_j, n_j, p_j}{\text{Min}} \ (L_t(n_j,\, p_j)) \tag{10}$$

Where L_t represents the priority order.

2.2.2.3. Compromise programming (CP). The first step in compromise programming is to determine the ideal point of each objective. This point can be achieved by optimizing each of the goals individually and according to the resource constraints (Yu, 1973; Zeleny, 1974). Because of the conflict between goals, reaching the ideal points is usually unlikely. Hence, the compromise solution are given by the closest solution to the ideal point which can be set based on the L_p-norm distance. The objective function is as follows and the constraints are the same as Eqs. (6)–(9):

$$\min_{x_i, f_j} \left(\sum_j \left| \frac{(f_j - f_j^*).\, w_j}{(f_j^* - f_j^{**})} \right|^{\rho} \right)^{1/\rho} \tag{11}$$

Where f_j^* is the ideal and f_j^{**} is the anti-ideal solution for the jth criteria. The parameter ρ, varying from one to infinite, shows the importance of the maximal deviation from the ideal point. The larger the value of the ρ, the greater the importance.

3. Study area

3.1. Hablehroud watershed

Hablehroud is a great watershed located in Tehran and Semnan provinces with the area of 1.2 million hectares. Its geographic location is between 51°39′ to 53°08′ E longitude and 34°26′ to 35°57′ N latitude (Fig. 1). With major rivers such as Delichai, Kilan, Nemrud and Hablehroud flowing from the north to the south, this is one of the sub-watersheds of the Great Salt desert located in the Irano-Turanian region. This watershed has three climatic zones including semi-arid climate in the north, arid climate in the boundary region of the north and the south and the semi-arid and desert and arid climate in the south. The precipitation regime is Mediterranean, with the rainy season from mid-November to mid-May and the dry season concentrated in the summer. The average annual rainfall is 159.6 mm (Azimi et al., 2014). Most areas of the watershed have the slopes between 15.1 % and 30 %. The minimum altitude is 1000 m and the maximum one is 4036 m.

3.2. Hablehroud watershed land uses

The present land-use pattern in the watershed consists of three major land-use types: cropland, horticulture, and rangeland. Here, a conservation land-use type was determined as the fourth major land-use type based on the studies in the SMLWR project as well as the experts opinions (Salman Mahini et al., 2014). In addition, the area of the current land-use pattern and the ecological potential area or the target area to allocate each of these four land-use types were determined accordingly (Table 1). The land-use sets or the decision variables are as follows:

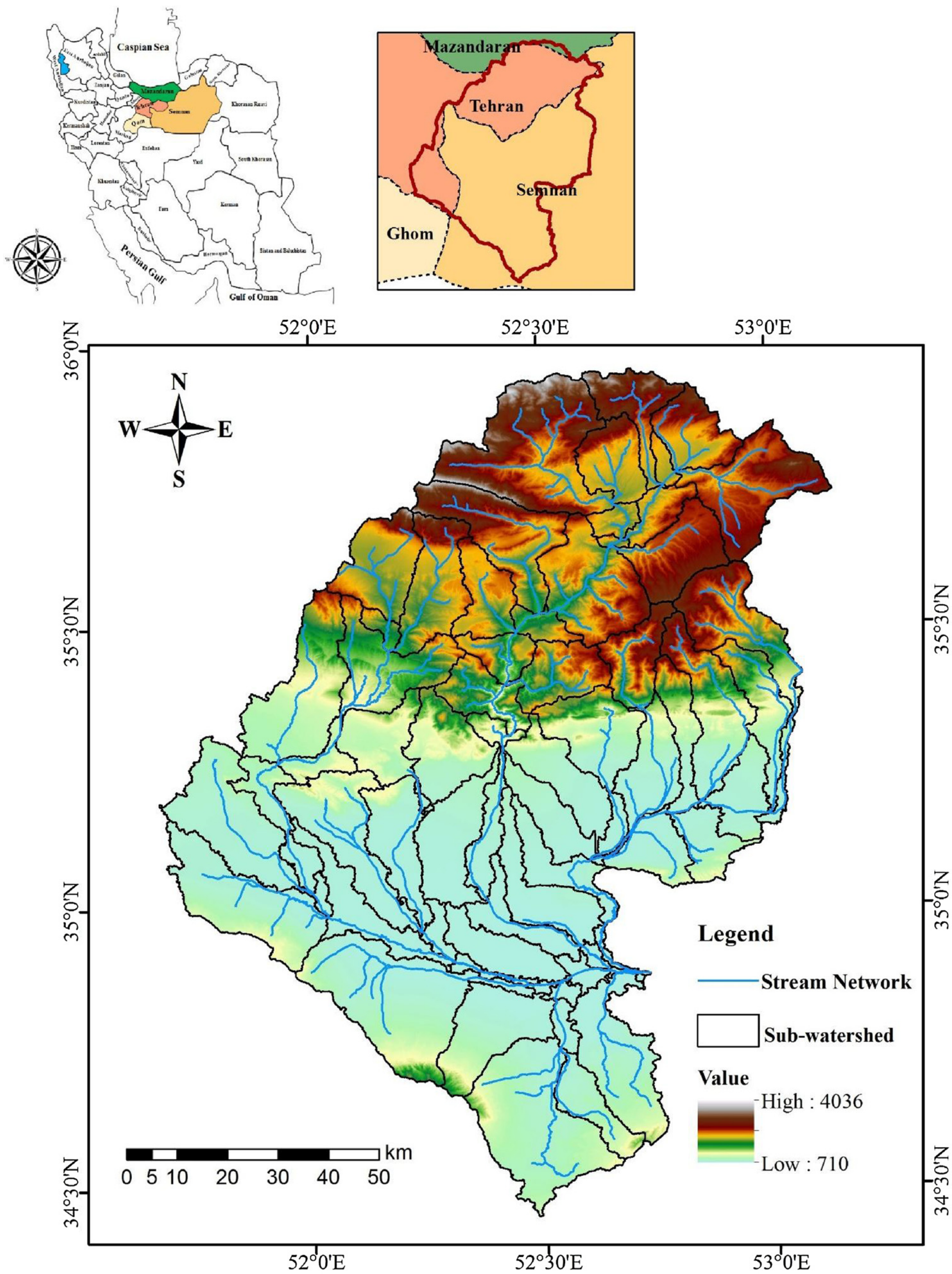

Fig. 1. Map of Iran (top left), location of the Hablehroud watershed (top right) and distribution map of the watershed showing sub-watershed borders and stream network with a digital elevation model of 30 m resolution (bottom).

Table 1
Current area and target area of each land-use type in the Hablehroud watershed. The data could be used to determine the land-use constraints as well as to calculate the criteria changes after optimization.

Land use	Current area(ha)	Target area(ha)
X1	33928	62230
X2	36986	76059
X3	9038	23990
X4	2172	35986
X5	497262	92762
X6	374721	75896
X7	0	46381
X8	0	37948

X1: cropland area in the north of the watershed (ha); X2: cropland area in the south of the watershed (ha); X3: horticultural land area in the north of the watershed (ha); X4: horticultural land area in the south of the watershed (ha); X5: rangeland area in the north of the watershed (ha); X6: rangeland area in the south of the watershed (ha); X7: conservation land area in the north of the watershed (ha); X8: conservation land area in the south of the watershed (ha).

3.3. Criteria for the Hablehroud watershed land uses

From the environmental aspect, the watershed is facing with high soil degradation. The difference in height and slope between the north and south of the watershed is 4,000 m and 60 percent, respectively. Therefore, with the most rainfall intensity in the north, soil erosion rate is high at the watershed with high surface runoff and sediment yield. Such environmental impacts which also results in nutrient losses from the lands, would seriously affect the watershed's economy. From the socio-economic aspect, agriculture and livestock are the main sources of income and employment in the watershed. More land allocation to these activities means more production values and costs and more jobs. Therefore, following Cisneros et al. (2011) and based on the environmental, economic and social characteristics of the watershed, the criteria are as follows:

3.3.1. Environmental criteria

1 Runoff: The average annual runoff yield per hectare of the land-use sets (m^3/ha.y)
2 Sediment: The average annual sediment yield per hectare of the land-use sets (ton/ha.y)
3 Erosion: The average annual erosion yield per hectare of the land-use sets (ton/ha.y)

3.3.2. Economic criteria

1 Income: The average annual gross production value per hectare of the land-use sets (10^4mIR/ha.y)
2 Cost: The average annual production cost per hectare of the land-use sets (10^4mIR/ha.y)

3.3.3. Social criteria

Employment: The average annual employment per hectare of the land-use sets (man-day/ha.y)

The linear relationships between the decision variables and these criteria are summarized in Table 2. The values of the environmental criteria were obtained through the simulations via the SWAT model, and the values of the socio-economic criteria were collected through field observations and questionnaires.

3.4. Constraints of the land uses

Constraints for the criteria are as follows (Table 3):

1 Maximum runoff: The maximum amount of runoff that can be produced throughout the watershed.
2 Maximum sediment: The maximum amount of sediment that can be produced throughout the watershed.
3 Maximum erosion: The maximum amount of erosion that can be produced throughout the watershed.
4 Maximum cost: The maximum amount of the production costs possible throughout the watershed.
5 Minimum income: The minimum amount of the acceptable income throughout the watershed.
6 Minimum employment: The minimum amount of the acceptable employment rate throughout the watershed.

For calculating each of the above values, maximum/minimum amount of each criterion for each land-use type is multiplied by its area, then summed up to get the overall value.

In addition to the above constraints, a set of other constraints were put into the model to validate the solutions. These constraints are as follows (Table 3):

7 Total watershed area: Calculated for both the northern and the southern parts, the values are obtained by summing the ecological target areas of all the land uses defined in Table 1.
8 Maximum area of the land-use types: The target area of the each land-use types obtained from Table 1 determined as the maximum lands available. The area is also calculated for both the northern and the southern parts.
9 Minimum area of the land-use types: The current area of the each land-use types obtained from Table 1 determined as the minimum lands required.

Based on the expert opinion, the rangeland constraint must be set equals to its target because in official documents the current land-use area is nominally larger than the area in practice.

4. Results and discussion

4.1. Payoff matrix for criteria and decision variables; set of goals and ideal and anti-ideal points

The first step in applying multi-objective optimization methods is to form a payoff matrix for the decision variables and criteria (Ballestero and Romero, 2013). Table 4 shows the payoff matrix determined by optimizing each of the criterion. The Runoff, Sediment, Erosion and Cost criteria were optimized towards their minima, whereas the Income and Employment criteria were optimized towards their maxima.

The payoff matrix for the criteria was determined by the previously defined technical coefficients and the payoff matrix for the decision variables (Table 5). The ideal points, bolded in the table, and the anti-ideal points, italicized in the table, were established in this matrix and the goals were defined accordingly via $gb_j = anti\_ideal_j + t_j.\,(ideal_j - anti\_ideal_j)$ (Antón et al., 2012). Where t_j was determined by the experts, the values of the goals were calculated as 1848348 (m^3/ha.y) for Runoff, 488222 (t/ha.y) for Sediment, 570588 (t/ha.y) for Erosion, 1932827 (10^4mIR/ha.y) for Cost, 4644659 (10^4mIR/ha.y) for Income and 15122149 (man-day/ha.y) for Employment.

4.2. Determining scenarios

To investigate the conflict between the social, economic, and environmental criteria (objectives) and provide policy indications, three scenarios were defined based on the studies by Anton et al. (2016) and Cisneros et al. (2011). According to the results of the AHP method, the highest weights were assigned to the socio-economic criteria and the

Table 2
Technical coefficient matrix of linear programming in application of the MCDM for the Hablehroud case study. The data shows a linear relationship between each of the criteria with one hectare of each land-use type.

Criteria/ Land use	Environmental			Economic		Social
	Runoff (m^3/ha.y)	Sediment (t/ha.y)	Erosion (t/ha.y)	Cost (10^4mIR/ha.y)	Income (10^4mIR/ha.y)	Employment (man-day/ha.y)
X1	4.44	2.78	2.83	7.64	11.56	41.95
X2	0.67	0.57	0.91	6.17	11.65	34.4
X3	10.69	4.34	5.8	22.54	58.69	204.52
X4	0.48	0.08	0.3	22.04	55.75	202.59
X5	13.59	2.52	2.67	0.44	2.81	7.23
X6	0.11	0.05	0.22	0.24	1.95	2.32
X7	12.23	2.27	2.4	0	0	0
X8	0.1	0.05	0.19	0	0	0

Table 3
Model criteria and land-use constraints for the Hablehroud case study. The equations are common in each of the three (WGP, LGP and CP) optimization model.

Model criteria constraint	Equation
Maximum runoff (m^3/ha.y)	$4.44X1 + 0.67X2 + 10.69X3 + 0.48X4 + 13.59X5 + 0.11X6 + 12.23X7 + 0.1X8 \le 5740393$
Maximum sediment (t/ha.y)	$2.78X1 + 0.57X2 + 4.34X3 + 0.08X4 + 2.52X5 + 0.05X6 + 2.27X7 + 0.05X8 \le 3716321$
Maximum erosion (t/ha.y)	$2.83X1 + 0.91X2 + 5.8X3 + 0.3X4 + 2.67X5 + 0.22X6 + 2.4X7 + 0.19X8 \le 2029697$
Maximum cost (10^4mIR/ha.y)	$7.64X1 + 6.17X2 + 22.54X3 + 22.04X4 + 0.44X5 + 0.24X6 \le 11633303$
Minimum income (10^4mIR/ha.y)	$11.56X1 + 11.65X2 + 58.69X3 + 55.75X4 + 2.81X5 + 1.95X6 \ge 1798536$
Minimum employment (man-day/ha.y)	$41.95X1 + 34.4X2 + 204.52X3 + 202.59X4 + 7.23X5 + 2.32X6 \ge 3208744$
Model land use constraint	Equation
Maximum cropland area(ha)	$X1 + X2 \le 138289$
Minimum cropland area(ha)	$X1 + X2 \ge 70913$
Maximum horticultural land area(ha)	$X3 + X4 \le 59976$
Minimum horticultural land area(ha)	$X3 + X4 \ge 11210$
Maximum conservation land area(ha)	$X6 + X7 \le 29515$
Total rangeland area(ha)	$X5 + X6 = 168659$
Maximum cropland area in north(ha)	$X1 \le 62230$
Maximum cropland area in south(ha)	$X2 \le 76059$
Maximum horticultural land area in north(ha)	$X3 \le 23990$
Maximum horticultural land area in south(ha)	$X4 \le 35986$
Maximum rangeland area in north(ha)	$X5 \le 92762$
Maximum rangeland area in south(ha)	$X6 \le 75896$
Maximum conservation land area in north(ha)	$X7 \le 46381$
Maximum conservation land area in south(ha)	$X8 \le 37948$
Total lands in north	$X1 + X3 + X5 + X7 = 178982$
Total lands in south	$X2 + X4 + X6 + X8 = 187941$

lowest were assigned to the environmental ones. This result was selected as the first scenario. In the second scenario, equal weights were assigned to all of the criteria which eliminates any expert's weight and, to make a contrast with the first scenario, the highest weights were assigned to the environmental criteria in the third scenario (Table 6). After determining the scenarios, the optimal values of the decision variables were obtained using GAMS software.

4.3. Multi objective models

4.3.1. Weighted goal programming model

Table 7 shows the results of the land-use optimization in all the three scenarios. Given the current and the target land-use areas under the first scenario, the horticultural land-use area in the north did not reach to its target despite increasing from its current level and this amount of decrease from the target capacity turned into the conservation area in the north. Other land uses were increased to their targets. The same was repeated to the second scenario, except that the horticultural land-use area in the north was set less than the current level. Under the third scenario, the cropland area in the south and the horticultural land-use area in the north did not reach their target despite increasing from their current level and these amounts of decrease from the target capacity turned into the conservation area both in the north and the south. The overall level of the conservation area in this scenario was greater than the level in the first. Here, the other land uses increased to their targets. To investigate the outcomes of these three scenarios, the subsequent results were compared for the criteria with two indexes: 1) goal achievement level of each criterion which was calculated based on the optimized land-use area multiplied by the related coefficients in the technical coefficient matrix. The values were compared to the goals; and 2) changes made from the current criteria values in the watershed. First, both the current land-use area and the optimized one were multiplied by the related coefficients in the technical coefficient matrix. Then, the obtained values were compared (Table 8).

According to Slaman Mahini et al. (2014), the current level of each criterion is as follows: 7070365 (m^3/ha.y) for Runoff, 1429021 (t/ha.y) for Sediment, 1591232 (t/ha.y) for Erosion, 1048248 (10^4mIR/ha.y) for Cost, 3601725 (10^4mIR/ha.y) for Income and 9447053 (man-day/ha.y) for Employment. In addition, a profit criterion calculated by subtracting the Income from the Cost was determined to compare these criteria more accurately. The current value of this criterion is 2553476 (10^4mIR / ha.y). Under the Index 1, Table 8 indicated that the third scenario had the highest goal achievement of 97 % on average. Under the Index 2, results indicated that the amounts of the environmental criteria decreased significantly and the amounts of the socio-economic criteria increased in all the three scenarios. The Profit criteria value increased in the first scenario and decreased in the second and remained unchanged in the third from its current value. Therefore, considering the slight differences between the scenarios with respect to their goal achievements and a positive profit value of the first scenario (2%), this scenario showed a better result with an emphasis on the socio-economic criteria.

4.3.2. Lexicographic goal programming model

In this method, different lexicographic orders of criteria

Table 4
Payoff matrix for the decision variables in the Hablehroud case study. In the table each of the criteria is optimized individually.

Criteria/ Land use	Min Runoff (m^3/ha.y)	Min Sediment (t/ha.y)	Min Erosion (t/ha.y)	Min Cost (10^4mIR/ha.y)	Max Income (10^4mIR/ha.y)	Max Employment (man-day/ha.y)
X1	62230	39839	39839	28629	62230	62230
X2	38111	38111	38111	74096	76059	76059
X3	23990	0	0	11210	23990	23990
X4	35986	35986	35986	0	35986	35986
X5	92762	92762	92762	92762	92762	92762
X6	75896	75896	75896	75896	75896	75896
X7	0	46381	46381	46381	0	0
X8	37948	37948	37948	37948	0	0

Table 5
Payoff matrix for the criteria in the Hablehroud case study. The table shows the amount of the criteria when each of them is optimized individually. It also shows the possible range of changes in amount of each criteria.

Criteria/ Optimization	Runoff (m^3/ha.y)	Sediment (t/ha.y)	Erosion (t/ha.y)	Cost (10^4mIR/ha.y)	Income (10^4mIR/ha.y)	Employment (man-day/ha.y)
Min Runoff	**1848348**	541566	631869	2103718	4986348	16964790
Min Sediment	2059357	**480093**	540963	1391823	3319424	11119014
Min Erosion	2059357	480553	**541118**	1391823	3319424	11119014
Min Cost	*2136174*	515483	596166	**987611**	*2260783*	*6888863*
Min Income	1869823	*561378*	*658996*	*2337920*	**5428325**	18270091
Min Employment	1869823	*561378*	*658996*	*2337920*	5428489	**18270590**

Note: The ideal points are in bold and the anti-ideal points are in italics.

Table 6
Experts' weights on the criteria and policy scenarios for the Hablehroud case study. Scenario1 shows the expert weights with higher weights on the socio-economic criteria. Scenario2 is neutral with equal weights on criteria. Scenario3 with higher weights on the environmental criteria is the opposite of the scenario1.

Criteria/scenarios	Runoff	Sediment	Erosion	Cost	Income	Employment
Scenario1	0.102	0.059	0.153	0.142	0.222	0.323
Scenario2	0.166	0.166	0.166	0.166	0.166	0.166
Scenario3	0.323	0.222	0.142	0.153	0.059	0.102

Table 7
Results of the weighted goal programming model in the study area. The table shows the optimal area of each land-use type in every scenario.

Scenario / Land use	Scenario1	Scenario3	Scenario3
X1	62230	62230	62230
X2	76059	76059	38111
X3	10638	8596	14979
X4	35986	35986	35986
X5	92762	92762	92762
X6	75896	75896	75896
X7	13353	15394	9011
X8	0	0	37948

Table 8
Results of optimization for the criteria. The level of goal achievements for the criteria and the changes made from the current criteria values in the study area.

Criteria	Scenario1		Scenario2		Scenario3	
	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)
Runoff	98	−73	98	−73	99	−74
Sediment	91	−63	92	−63	93	−63
Erosion	93	−61	94	−62	95	−62
Cost	95	94	97	90	98	81
Income	100	29	97	26	96	24
employment	97	64	100	60	100	60
profit		2		−1		0
Average achievement	96 %		96 %		97 %	

Index 1: goal achievement level of each criterion after optimization in percent; Index 2: percent change of criteria values after optimization.

optimization were used with the same goal levels. The lexicographic order was set based on the expert opinion to investigate the conflict between the economic and the environmental goals in a different procedure. In scenario one, the economic criteria were prioritized first in order: 1st Income, 2nd Cost. In scenario two, the social criterion (Employment) was optimized first and in scenario three the environmental criteria were prioritized first in the order: 1st Runoff, 2nd Sediment and 3rd Erosion. Tables 9 and 10 summarizes the results of the LGP. Table 9 indicated that under the first and the second scenarios, all of the land-use areas reached to their targets except the conservation

Table 9
Results of the lexicographic goal programming model in the study area. The table shows the optimal area of each land-use type in every scenario.

Scenario / Land use	Scenario1	Scenario3	Scenario3
X1	62230	62230	62230
X2	76059	76059	76059
X3	23990	23990	11210
X4	35986	35986	0
X5	92762	92762	92762
X6	75896	75896	75896
X7	0	0	12780
X8	0	0	35986

Table 10
Results of optimization for the criteria. The level of goal achievements for the criteria and the changes made from the current criteria values in the study area.

Criteria	Scenario1		Scenario2		Scenario3	
	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)
Runoff	99	−74	99	−74	99	−73
Sediment	87	−61	87	−61	91	−63
Erosion	87	−59	87	−59	93	−62
Cost	83	123	83	123	65	20
Income	86	51	86	51	58	−26
employment	83	93	83	93	100	60
profit		21		21		−45
Average achievement	87 %		87 %		84 %	

Index 1: goal achievement level of each criterion after optimization in percent; Index 2: percent change of criteria values after optimization.

land-use area. In the third scenario, the horticultural land-use area in the south was removed and the horticultural land-use area in the north did not reach to its target despite increasing from its current level. This amount of decrease from the target capacity turned into the conservation area both in the north and the south. Since the removal of the horticultural land-use area in the south of the watershed is not a viable solution, this scenario seems inappropriate at the initial investigation. Under the Index 1, Table 10 indicated that the social and the economic scenarios had the highest goal achievements of 87 % on average. Under the Index 2, results indicated that the amounts of the environmental criteria decreased significantly and the amounts of the socio-economic criteria increased in all the three scenarios. Therefore, considering the goal achievements levels and a positive profit value of the first and the second scenarios (21 %), these scenarios showed better results with an emphasis on the socio-economic criteria.

4.3.3. *Compromise programming model*

In this method, the ideal and anti-ideal points for each of the criteria were determined through the results of the Table 5. In the next step, model estimation was performed for three classical metric distances ($\rho = 1, \rho = 2$ and $\rho = \infty$) and for the three socio-economic, neutral and environmental scenarios. Unlike the previous models, the results of

Table 11
Results of the compromise goal programming model for ρ = 1, ρ = 2 and ρ = ∞ metrics in the study area. The table shows the optimal area of each land-use type in every scenario.

Land use	Scenario1			Scenario2			Scenario3		
	ρ = 1	ρ = 2	ρ = ∞	ρ = 1	ρ = 2	ρ = ∞	ρ = 1	ρ = 2	ρ = ∞
X1	62230	62230	39976	62230	62230	49966	62230	62230	53154
X2	38111	38111	46225	38111	38111	40353	38111	38111	38111
X3	23990	17486	18275	0	3541	7799	0	0	13852
X4	35986	35986	35824	35986	35986	35520	35986	35986	35986
X5	92762	92762	92762	92762	92762	92762	92762	92762	92762
X6	75896	75896	75896	75896	75896	75896	75896	75896	75896
X7	0	6504	27969	23990	20450	28455	23990	23990	19214
X8	37948	37948	29995	37948	37948	36171	37948	37948	37948

Table 12
Results of optimization for the criteria (ρ = 1). The level of achievements to the ideal points for the criteria and the changes made from the current criteria values in the study area.

ρ = 1	Scenario1		Scenario2		Scenario3	
Criteria	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)
Runoff	100	−74	98	−73	98	−73
Sediment	89	−62	98	−66	98	−66
Erosion	86	−60	98	−65	98	−65
Cost	47	101	63	49	63	49
Income	92	38	66	−1	66	−1
employment	93	80	66	28	66	28
profit		13		−21		−21
Average achievement	84 %		82 %		82 %	

Index 1: achievement level of each criterion to the ideal points after optimization in percent; Index 2: percent change of criteria values after optimization.

Table 13
Results of optimization for the criteria (ρ = 2). The level of achievements to the ideal points for the criteria and the changes made from the current criteria values in the study area.

ρ = 2	Scenario1		Scenario2		Scenario3	
Criteria	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)
Runoff	99	−74	98	−73	98	−73
Sediment	91	−63	96	−65	98	−66
Erosion	89	−62	96	−65	98	−65
Cost	50	87	60	57	63	49
Income	85	28	70	5	66	−1
employment	86	65	70	35	66	28
profit		4		−16		−21
Average achievement	83 %		82 %		82 %	

Index 1: achievement level of each criterion to the ideal points after optimization in percent; Index 2: percent change of criteria values after optimization.

Table 14
Results of optimization for the criteria (ρ = ∞). The level of achievements to the ideal points for the criteria and the changes made from the current criteria values in the study area.

ρ = ∞	Scenario1		Scenario2		Scenario3	
Criteria	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)	Index 1 (%)	Index 2 (%)
Runoff	91	−71	94	−72	96	−73
Sediment	92	−63	95	−65	93	−64
Erosion	89	−62	94	−64	91	−63
Cost	53	77	60	57	55	72
Income	83	24	72	8	79	19
employment	83	60	72	39	79	54
profit		3		−12		−3
Average achievement	82 %		81 %		82 %	

Index 1: achievement level of each criterion to the ideal points after optimization in percent; Index 2: percent change of criteria values after optimization.

each scenario for the criteria were compared with the ideal points. The results of the ρ = 1 metric shown in Table 11 indicated that under the first scenarios, the cropland area in the south did not reach to its target despite increasing from its current level. And this amount of decrease from the target capacity turned into the conservation area in the south. Other land uses increased to their targets. The same repeated to the second and the third scenarios, except that the horticultural land-use area in the north was removed. Since the removal of the horticultural land-use area in the south of the watershed is not a viable solution, this scenario seems inappropriate at the initial investigation. Under the Index 1, results from Table 12 indicated that the first scenario had the highest achievement of 84 % to the ideal points on average. Under the Index 2, results indicated that the amounts of the environmental criteria decreased significantly and the amounts of the socio-economic criteria increased in all the three scenarios. The Profit criteria value increased in the first scenario and decreased significantly in the second and the third ones from their current values. Results of the ρ = 2 metric shown in Table 11 indicated that under the first scenarios, the cropland area in the south and the horticultural land-use area in the north did not reach to their targets despite increasing from their current levels and these amounts of decrease from the target capacity turned into the conservation area in the watershed. The difference between the first and the second scenarios was in the amount of the horticultural land-use area in the north which in the second scenario was lower than its current value. In the third scenario the horticultural land-use area in the north was removed which is not a viable solution. Results from Table 13 were similar to Table 12 but with different values. Results of the ρ = ∞ metric shown in Table 11 indicated that under the first scenarios, only the rangeland area throughout the watershed reached to its target but other land uses determined lower than their targets and upper than their current values. The same was repeated for the second scenario except that the horticultural land-use area in the north was determined lower than its current value. In the third scenario, the horticultural land-use area in the south and the rangeland area throughout the watershed reached to their targets but other land uses determined lower than their targets and upper than their current values. Results from Table 14 indicated that the first and the third scenarios had the highest achievement to the ideal points on average. Other results were the same as the results of the Table 13 and the Table 12 but with different values. Similar to the WGP method, in this method for all of the three metric distances, most of the changes in the areas were related to the horticultural land-use area in the north and the cropland area in the south. Here, for all the three metric distances, the first scenarios revealed better outcomes and among these scenarios, the ρ = 1 metric yielded a better result.

Several studies in land-use planning have indicated the existence of conflicts between objectives especially in agricultural land-use allocation problems (Cui et al., 2018; Kaim et al., 2018; Kim and Arnhold, 2018; Strauch et al., 2019; Zhou et al., 2017). According to the results of Tables 4 and 5, a level of conflict existed between the environmental and the socio-economic objectives. The conflict could be recognized through land-use allocation in Table 4 and criteria optimization in Table 5. In Table 4, each objective achieved its optimal value independent of the other objectives. As the economic criteria such as Income and Employment optimized to their maxima, no land were allocated to conservation as an environmentally friendly land-use type; whereas for minimization of Runoff, Sediment and Erosion as the environmental criteria, eco-friendly lands from crops and horticultural uses were allocated to the conservation area. In Table 5, the amount of each criteria were calculated based on the optimum level of each objective shown in Table 4. Indeed, the optimal values of the economic criteria such as Income and Employment matched the worst values of the environmental criteria such as Sediment and Erosion. Also, the Cost at the optimal value had conflicts with the Runoff and both the Income and the Employment criteria. These results confirmed the existence of conflicts between the economic and environmental objectives. Therefore, it is only possible to choose one objective or reach a compromise between them.

All the three methods incorporated in this study dealt with a specific problem from their own points of view. Using AHP to weight the criteria by the experts, the WGP and the CP used the weights to form the scenarios while the LGP used the expert opinions to set different lexicographic orders of the criteria optimization. Both the WGP and the LGP methods used the same aspiration levels or goals while the CP used the ideal point levels instead. Results under the Index 1 (Tables 8 and 10) for the first and the second scenarios showed the average goal achievements of 96 % for WGP and 87 % for LGP. For the third scenario the average goal achievement was 97 % for WGP and 84 % for LGP. Despite the lower profit, the results of the WGP method were more compatible with the goals than the LGP. As the LGP results shown in Table 10, decision makers would get away from the goals if they priorities the environmental criteria, while for WGP results shown in Table 8 it is not the case. Comparing the total conservation land area allocated in WGP (75707 ha) with those in the LGP (48766 ha) revealed that the more lands allocated to the conservation use, the more achievement to the goal levels (Tables 7 and 9). The results of the CP method were highly compatible with the ideal points. Results under the Index 1 (Tables 12–14) for the first scenario showed the average achievements of 84 % for $\rho = 1$, 83 % for $\rho = 2$ and 82 % for $\rho = \infty$ to the ideal points. For the second scenario the average achievement was 82 % for $\rho = 1$, 82 % for $\rho = 2$ and 81 % for $\rho = \infty$ to the ideal points and for the third scenario the average achievement was 82 % for all the three ρ metrics. High ρ metric value which means more sensitivity to the deviation from the ideal points, led to more conservation land-use allocation. Altogether, it could be concluded that if the decision makers want to get closer to the goals, more lands should be allocated to the conservation area but if they want to get closer to the ideal points, less conservation lands should be allocated. According to the constant values of the range land areas after the optimization, more conservation land-use area means less horticultural and crop land-use areas and vice versa. Therefore, the decision-makers' priorities for watershed management play an important role in selecting an appropriate method.

Introducing scenarios could reveal the different impacts of each policy on the criteria and the decision variables, so that the decision makers could investigate the effects of each policy in details. Currently, the watershed is facing different environmental problems such as soil erosion and sedimentation. Results under the Index 2 for the first scenario showed that the environmental criteria decreased about 66 % in WGP, 64 % in LGP and 65.3 % in CP, all on average. For the second scenario the criteria decreased about 66 % in WGP, 64 % in LGP and 67.6 % in CP and for the third scenario the criteria decreased about 66 % in WGP, 66 % in LGP and 67.3 % in CP. Given such a significant decreases after the optimization verifies that the current land-use pattern does not take the environmental aspects into account. With no significant difference among the method results, it can be concluded that land-use optimization could improve environmental situation throughout the watershed apart from the methods or the scenarios applied.

Facing different socio-economic problems, the studies in the watershed show that more than half of the villages have been evacuated due to the migrations to the cities. Results under the Index 2 for the first scenario showed that the social criterion increased 64 % in WGP, 93 % in LGP and 68 % (on average) in CP. For the second scenario the criteria increased about 60 % in WGP, 93 % in LGP and 34 % (on average) in CP and for the third scenario the criteria increased about 60 % in WGP, 60 % in LGP and 36 % (on average) in CP. These results revealed the great effects of land-use optimization on employment in the watershed. Among the methods, the socio-economic scenarios of the LGP had the greatest impact on employment. As shown in the Table 9, the method proposed allocation of all the land-use types up to their target levels except for the conservation lands with no area to allocate. This implies that the highest employment rate is at the expense of the conservation lands omission. Considering the profit as an economic criteria, results indicated that the profit value increased 2 % in WGP, 21 % in LGP and 6% (on average) in CP, but only in the first scenario. Other scenarios except for the second one in the LGP (which is a social scenario), resulted in negative or neutral economic effect regardless of the method used. Therefore, the first scenario could be recommended to the decision makers prior to the others. Among the methods, the LGP had the greatest impact on profit criteria with the same consequences on the land-use allocation as the employment criteria in the LGP method. Consider that due to the conflict between the social, the economic and the environmental criteria, shown in Table 5, simultaneous achievement of these goals is unlikely (Cisneros et al., 2011). Anyway, the investigation of the results in all the three methods revealed that the socio-economic scenario was the most favorite in general. Whether based on the goal achievements or the ideal points, selecting the first scenario in all of the methods indicated that the economic improvement should be considered as a priority for all of the planning projects in the watershed. Overall, as mentioned in the Introduction, investigating different optimization methods allow the decision makers to evaluate the trade-offs between environmental, social and economic objectives and to assess the efficiency of current land uses (Kennedy et al., 2016).

The whole range of the optimal solutions comprises much more information to the decision makers and better reflects their points of view (Memmah et al., 2015). In all the given solutions, the horticultural land use and then the cropland use areas had the highest increase in land allocation respectively – compared to their current situations. This result is reasonable considering the high profitability of the horticultural activities in the watershed. Meanwhile, the horticultural land-use area in the south had the biggest increase in all the methods which is in line with the observations of the researchers about the increasing tendency of the farmers in the south of the watershed to change the current land uses to the horticultural one. Thus, policy-making is important in allocating the facilities to guide the land-use changes, especially towards the horticulture use in the south of the watershed. Moreover, the rangeland use area was significantly decreased compared to its current area which can be justified by the extent of the watershed area. It could also confirm the validity of the assumptions of the rangeland use constraints based on the fact that the capacity presented in the reports was nominal.

5. Conclusions

The current study investigated the optimal land-use allocation methods based on the economic, social and environmental criteria in the Hablehroud watershed via a soil and water assessment tool (SWAT) model and multi criterion decision-making (MCDM) methods. The importance of the watershed as a food supply center and the socio-economic problems such as migration, unemployment and low-income populations besides the environmental problems such as soil erosion and sedimentation, necessitates comprehensive studies to deal with such problems. Most of the studies uses a particular method or procedure to investigate land-use problems but this study tried to investigate the problem by combining different procedures and methods. Results of the pay-off matrix both for the criteria and the decision variables indicated the conflict of interests between the objectives. The criteria weights given by the experts revealed their emphasis on prioritization of the economic objectives which were confirmed by the optimization results of the three multi-objective methods. The environmental criteria decreased significantly in all the methods and scenarios after the optimization, and the socio-economic criteria were increased and improved particularly in the first scenario showing better results in all the methods. Therefore, the study recommended prioritizing the socio-economic objectives in management plans alongside allocating more lands to the conservation area. Besides, the optimal patterns provided in this study were suggested to reduce harmful environmental impacts of the current land-use pattern and improve the overall socio-economic conditions of the watershed. The study showed how each method deals with a specific problem, how the results changes and differs in each method, what are the similarities between the results and how different scenarios show their impacts in each method. Consequently, the results of the study verified that these methods while dealing with the land-use optimization from different aspects could help decision makers in the watershed to choose more appropriate solutions. For the first time, the current study was carried out in a context of non-spatial optimization in the Hablehroud watershed. Yet, more studies from other aspects are needed in the region. One could be the comparison of the results between the non-spatial optimization models used in this study, with the spatial models. Due to the extent of the area of the watershed, it was divided into northern and southern parts. For future studies, we suggest the division of the area into smaller units and more detailed examination. Given the uncertainty an inaccuracy of data sets in land-use studies (Moradi and Limaei, 2018), we also suggest the use of fuzzy multi-objective programming methods as a more flexible and reliable approach than the traditional multi-objective ones.

CRediT authorship contribution statement

Amin Arjomandi: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Seyed Abolghasem Mortazavi:** Conceptualization, Validation, Supervision. **Sadegh Khalilian:** Conceptualization, Validation. **Arash Zare Garizi:** Methodology, Software, Formal analysis, Resources, Data curation, Writing - review & editing.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.landusepol.2020.104930.

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