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Optimizing land use pattern to reduce soil erosion

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Abstract

Soil erosion hazard is one of the main problems can affect ecological balance in watersheds. This study aimed to determine the optimal use of land to reduce erosion and increase the resident's income of Qushchi watershed in West Azerbaijan province, Iran. Income and expenses for the current land uses were calculated with field studies. Damages resulting from the soil erosion were estimated by soil depth equal to the specified land uses. For three different options including the current status of land uses without and with land management, and the standard status of land uses, multi-objective linear programming model was established by LINGO software. Then the optimization problem of the land use was solved by simplex method. Finally, the best option of land use was determined by comparing erosion rate and its cost in each scenario. Then the circumstances and the recommended conditions were compared. The results indicated that the current surface area of current land uses is not suitable to reduce erosion and increase income of residents and should change in the optimum conditions. At the optimum level, there should change horticulture area of 408 to 507 (ha), irrigated land area of 169 to 136 (ha) and dry farming of 636 to 570 (ha), while conversion of rangeland area not indispensable. In addition, the results showed that in case of the optimization of land use, soil erosion and the profitability of the whole area will decrease 0.75% and increase 3.68%, respectively. In case of land management practices, soil erosion will decrease 42.27% and the profitability increase 21.39% while in the standard conditions, soil erosion will decrease 60.95% and profitability will increase 24.20%. The results of the sensitivity analysis showed that the changes in the horticulture and range land areas have the greatest impact on the increasing profitability and reducing soil erosion of Qushchi watershed. So, it is recommended using Education and Extension to promote the importance of land management to understand how proper use of the land.

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Introduction

Sustainability of the agriculture and natural resources are known as an ecological phenomenon that is in relation to the average income security of the society and relies on the stability of renewable sources (Shively and Coxhead, 2004). The proper management of watersheds to achieve sustainability and most profitable is land use optimization using linear programming and geographic information systems considering conflicting views on the utilization of the earth's limited resources (Riedel, 2003). Although some researchers thought that finalizing dominant economic options should consider ecosystem sustainability and social issues (Pfaff and Sanchez, 2004) some others believe that the economic

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development of many communities is based on proper land use planning with economic respects (Pasour, 1983). The use of different optimization methods have been developed whereby most immersive and reasonable management actions associated with them so that spatial distribution of agricultural land in order to maximize profits modeled (Rounsevell et al., 2003). Both linear and nonlinear programming to optimize and achieve higher profits of land also used (Benli and Kodal, 2003). They resulted that the use of non-linear programming to maximize profits on agricultural land due to water restrictions is more suitable. Increasing of agricultural lands and forests productivity due to proper allocation of land to different uses was approved (Tra and Egashira, 2004). The results of the study by Singh and Singh (1999) showed that the planned cultivation has increased from 60% to 96% and net profit from 23% to 26% with optimizing land use. The appropriate allocation of different land uses was done using geographic information system integrated with optimization models with respect to existing land uses, slope and distance from surface water sources (Wang and Huang, 2004). The results of a research with the multi-linear programming model to optimize land use showed that the use of the resources, consistently improve rural people's income (Liu and Stewart, 2004). The optimal utilization of watersheds resources was determined using plan aimed method showed that the proposed model based on the perspective of economic has relative superiority on the social and environmental attitudes (Mohseny Saravi et al., 2001). Determining the optimal crop rotation using linear programming to obtain high net income and compare it in the current status and the sensitivity analysis showed that net farm income of the four optimal crop rotation and also, limiting inputs, have changes rather flexible (Gholami, 2003). Economical evaluation of the land allocation using linear programming model with respect to the limitations of the land transport, economic and environmental conditions, confirmed the promotion of the local economy with methods and changes in land displacement (Flah-Shamsi, 2004). Multi-purpose linear programming model was used to reduce the environmental and economic effects of soil erosion due to inappropriate management practices of land was used by Nikkami et al. (2002). They also showed that the optimum land use and land management practices can reduce soil erosion and increased income of users. The results show that sediment production decreased 5% and annual profits increased 134%. Linear programming was used to optimize land use that can minimize soil erosion (Jalili, 2004). The results introduced the optimum use of land, reduce erosion and increase the amount of annual profits 7.78% and 118.62%, respectively. Land use and erosion relationship were studied by Yueqin et al. (2011). They showed soil erosion significantly varied among land-use types. Erosion was most serious in dry farmland and the lightest in paddy field and conservation practices should be taken in these areas. Li et al. (2013) resulted that forest and wasteland land conversions induce substantial soil erosion, while transition from wasteland to forest retards soil loss. Analyzing the soil erosion of each land-use it was obtained the following land use erosion vulnerability: Olive orchard>Vineyard>Montado>Alfalfa. The strong erosion variances that were observed in the study area show the importance of locating the 'hot spots' of soil erosion (Ferreira, 2015). Since optimization methods in watershed management leads to conserve resources and provide the optimum solution to achieve sustainable use of land and in compliance with all technical, social, economic and legal restrictions that has not been done in the area. In this study, we have tried to select the best model of land optimization in the Qushchi watershed and its sensitivity to changes so that can designate users to conserve resources and reduce soil erosion.

Material and Methods

Study area

The study area of Qushchi watershed with the surface area of 5186 ha is located in the of West Azarbaijan province, IRAN, in, 44°51′10″ to ″44°57′52″ E and 37°56′01″ to 38° 00′ 53″. Figure 1 is depicted the location of the study area. The most common Agricultural activities are in form of subsistence and semi-mechanized without any soil and water conservation practices. People are living in difficult conditions and income is scarce. Facilities and infrastructure in the area is not appropriate.

Research Methodology

To determine major land uses including irrigated annual crops, rainfed lands, orchards and rangelands, satellite images (Google-Earth) interpretated by visual method to prepare land use map. Soil erosion was estimated using MPSIAC model. The cost and benefits of existing land uses were calculated with field studies. The amount of erosion damage was estimated by converting amount of soil erosion of a given land surface area and equivalent soil depth. The primary data about climate, geology, hydrology, land use and erosion needed to calculate final results were collected from Forests and Rangelands Organization, field interviews and Iran Statistics Center. Animal husbandry and its effects were considered in rangelands evaluation.

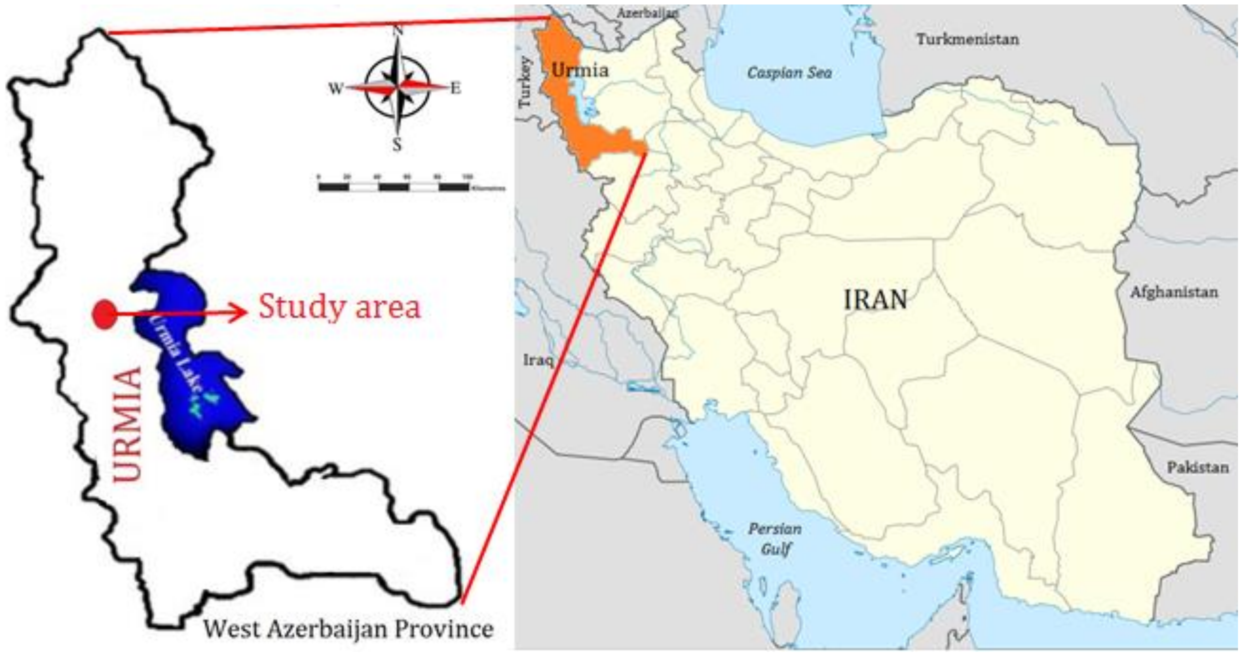

Figure 1. Location of the study area; Qushchi catchment

The land use optimization was carried out as the following three scenarios.

- The current status of land uses
- The current status of land use with land management
- Standard status of land use with soil and water conservation practices, low inputs and high outputs.

Optimizing of the land use pattern problem was solved with the aim of erosion reduction and increase farmers' income using LINGO software and the Simplex method (Equation 1):

$$\sum_{i=1}^{n} X_i = B$$
$$X_i \geq 0 \tag{1}$$

Where:
X_i: is the surface area of each land use (ha)
B: total surface area (ha)

Due to the linearity of the objective function, linear programming was selected and since the simplex method does not need to become multi-objective optimization to be a one goal, so it was used to solve the problem.

Multi-objective optimization problem with n decision variables and general constraints and p objective is provided in relations 2 to 8 (Benli & Kodal. 2003 and Singh. 2016). Using these relationships, the general issue for profit maximization function in the watershed is written as Equation 2.

$$\text{Max } (Z_1) = [(A_{i1} - A_{i2} + A_{i3}) X_i] \tag{2}$$

Equation 2 can be simplified as relation 3.

$$\text{Max } (Z_1) = C_{Bi}X_i \tag{3}$$

The general form for function minimization problem of erosion in the Qushchi watershed was written as a simple relationship 4.

$$\text{Min } (Z_2) = C_{Bi}X_i \tag{4}$$

Limited to:

$$X_1 = B \tag{5}$$
$$X_1 > 0$$

In these equations:
Z_1: the annual net income of the watershed (Euro/ year)
Z_2: annual erosion of the watershed (ton/ year)
X_i: The area of each land use (ha)

A_{i1}: annual gross income of each land use unit area Euro/year)
A_{i2}: unit production costs per user (Euro/ year)
A_{i3}: the cost of soil loss per unit area per land use types (Euro/ year)
C_{Bi}: profitability of each land use (Euro/ year)
C_{Bi}: erosion for each land use (ton/ ha/ year)
B: total surface area (ha)
To issue a more detailed description, for four land use of horticulture, rangeland, irrigated and dry farming was written as Equation (6).

$$Max (Z_1) = [(A_{11} x_1 - (A_{12} x_1 + A_{13} x_1)) + (A_{21} x_2 - (A_{22} x_2 + A_{23} x_2)) + (A_{31} x_3 - (A_{32} x_3 + A_{33} x_3)) + [(A_{41} x_4 - (A_{42} x_4 + A_{43} x_4))] \quad (6)$$

Equation (6) summarized to optimize profits in the form of equation (7).

$$Max (Z_1) = C_{B1} x_1 + C_{B2} x_2 + C_{B3} x_3 + C_{B4} x_4 \quad (7)$$

Also using equation (8) minimizing soil erosion in the study area was conducted.

$$Min (Z_2) = C_{E1} x1 + C_{E2} x_2 + C_{E3} x_3 + C_{E4} x_4 \quad (8)$$

$X_1 < B_1$
$X_3 < B_2$
$X_4 < B_3$
$X_1 + X_3 < B_4$
$X_1 + X_2 + X_3 + X_4 = B_5$
Limited to:
$X_1 > B_6$
$X_2 > B_1$ (9)
$X_1 + X_2 + X_3 + X_4 > 0$
In these equations:
X_1: the surface area of the gardens (ha)
X_2: Area of the rangelands (ha)
X_3: The area of irrigated lands (ha)
X_4: an area of the dry farming (ha)
A_{11}: gross income gardens per hectare (Euro/ ha)
A_{12}: Level of gardens cost of production per unit (Euro// ha)
A_{13}: Unit erosion damage from the gardens (Euro/ ha)
A_{21}: GDP per unit of rangelands (Euro/ ha)
A_{22}: cost of production per unit area of the rangelands (Euro/ ha)
A_{23}: Damage erosion of rangelands (Euro/ ha)
A_{31}: Unit gross income from irrigated lands (Euro/ ha)
A_{32}: cost of production per unit area of the irrigated lands (Euro/ ha)
A_{33}: erosion damage of the surface area of the irrigated lands (Euro/ ha)
A_{41}: GDP unit of the drylands (Euro/ ha)
A_{42}: cost of production per unit area of the drylands (Euro/ ha)
A_{43}: erosion damage unit of the drylands (Euro/ ha)
C_{B1}: annual net profit per hectare gardens (Euro/ ha)
C_{B2}: annual net profit per hectare of the rangelands (Euro/ ha)
C_{B3}: annual net profit per unit of the irrigated lands (Euro/ ha)
C_{B4}: annual net profit of the drylands (Euro/ ha)
C_{E1}: erosion per unit area gardens (ton/ ha/ year)
C_{E2}: erosion per unit area of the rangelands (ton/ ha/ year)
C_{E3}: erosion on irrigated land area (ton/ ha/ year)
C_{E4}: erosion per unit area of the drylands (ton/ ha/ year)
B_1: Max surface area of the gardens (ha)
B_2: surface area irrigated farming lands (ha)
B_3: surface area dryland farming lands (ha)
B_4: surface area of the gardens in addition to irrigated land area (ha)
B_5: the total surface area (ha)
B_6: Min surface area of the gardens (ha)
B_7: Min surface area of the rangelands (ha)

The problem of the optimizing land use pattern in Qushchi watershed, seven restrictions related to the land use, the amount of water, non-negative total area of land allocated for land use and land use optimization model variables were considered for the following two limitations, for example as follows.

The first limitation

This limitation was considered that 408 ha land area in the current status is garden, but this surface area can be increased to 507 ha. The reason for this increase is the possibility of allocating land with a slope and soil depth. This restriction is shown in relation 10.

$X1 < 507$ (10)

The second limitation

The second limitation is related to irrigated land (169 ha) but according to the standard conditions required for irrigation, soil and water availability, only 136 ha have irrigation potential and for this reason the surface area of land will decrease from 169 to 136 ha (relation 11).

$X3 < 136$ (11)

Finally, sensitivity to the changes in the ratio of 10 to 50% of the exchangeable resources, the optimum scenario of the land use and management was determined comparing of the erosion rate and profit of each option.

Results

Of total surface area, 3496 ha includes four types of land uses of gardens, rangeland with the most area, irrigated lands with the minimum surface area and dryland farming (Table 1). The minimum rate of erosion related to the gardens and maximum of it belongs to rangelands (Figure 2). The average slope is 27.4% that 85% of the area is located on the above 12% slope. Elevation ranges 1483 to 2716 meters above see level. Rock units mainly are sandstone and shale. The average rainfall in the area is about 300 mm per year. An area of the rangelands are about 2283 ha including sparse species, forbs, annual grasses and some types like the thymus.

Table 1. Mean value of the coefficients of the problem optimization in the current situation

Soil erosion damage	Net income	Gross income	Cost	Annual erosion (tons/ha/year)	Area (ha)	Land use
(Euro/ha/year)						
28.80	192.65	340.25	147.60	8	408	Horticulture
5.15	101.17	196.18	95.01	14	2283	Range
69.53	55.05	105.08	50.03	10	169	Irrigated Farm
18.47	61.60	71.02	9.42	12	636	Dry farming

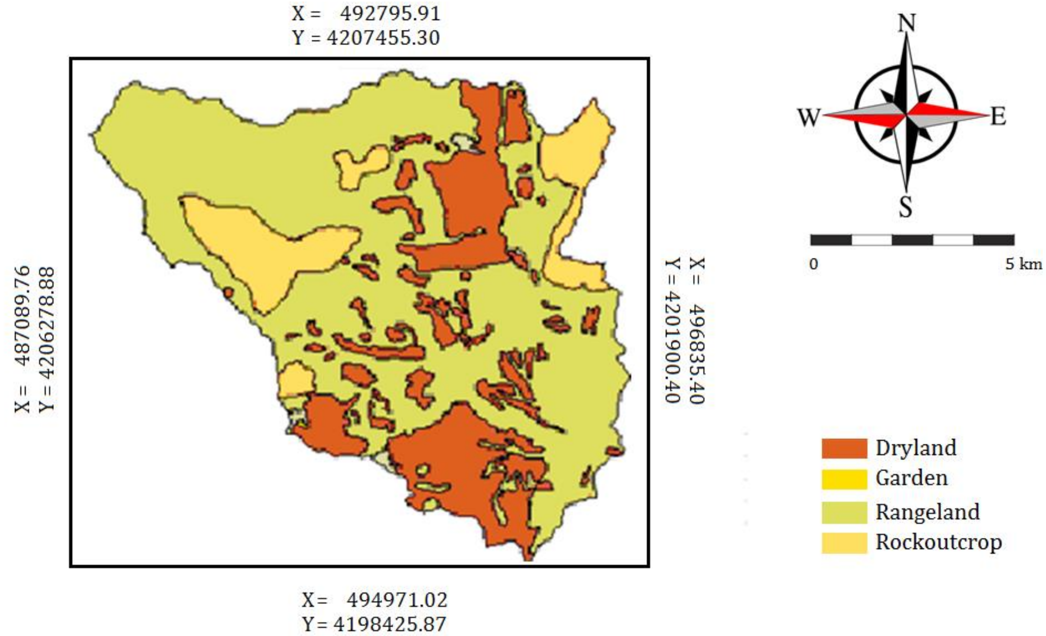

Figure 2. The land use map

Coefficients of the multi-objective optimization problem with n decision variables and constraints, and p goal in three options of: the current situation of land without land management, the current state of land with land management and land use in the standard status were presented in Table 1, 2 and 3.

Table 2. Mean value of the coefficients of the problem optimization of land management practices

Soil erosion damage	Net income	Gross income	Cost	Annual erosion (tons/ha/year)	Area (ha)	Land use
(Euro/ha/year)						
18.82	349.77	57.12	221.40	5	408	Horticulture
5.15	100.89	196.43	95.54	10	2283	Range
43.75	80.30	130.33	50.03	6	169	Irrigated Farm
16.49	57.14	66.00	8.86	9	636	Dry farming

Table 3. Mean value of the coefficients of the problem optimization in the standard setting

Soil erosion damage	Net income	Gross income	Cost	Annual erosion (tons/ha/year)	Area (ha)	Land use
(Euro/ha/year)						
6.32	349.77	571.17	221.40	4	507	Horticulture
2.88	100.14	196.43	95.54	9	2283	Range
25.03	82.83	132.86	50.03	4	136	Irrigated Farm
17.44	76.60	86.02	9.42	8	580	Dry farming

To achieve the most appropriate land use option, tables of simplex method for linear performance for land uses with targeted functions and constraints, was defined as an instance of the tables is provided on the current status of land use in Table 4.

Table 4. Simplex table for problem optimization of Qushchi land use in the current situation

Factors / Function	X1 Horticulture	X2 Range	X3 Irrigated Farm	X4 Dry farming	Function Type	Right position of Relationship
Objective Function 1	7706027.84	4046669.70	2202028.22	2464018.26	Max	0
Objective Function 2	-8	-14	-10-	-12	Max	0
Limitation 1	1	0	0	0	<	507
Limitation 2	0	0	1	0	<	136
Limitation 3	0	0	0	0	<	580
Limitation 4	1	0	1	0	<	643
Limitation 5	1	1	1	1	<	3496
Limitation 6	1	0	0	0	>	408
Limitation 7	0	1	0	0	>	2283

Table 4 shows that columns 2 to 5 in the left are decision variables and have the units of money and erosion in rows 2 and 3 respectively. Numbers one and zero in the rest of the rows indicates the presence or absence of the variable in the limits. Rows 2 and 3 in column 6 indicates the type of purpose equation for minimizing or maximizing, while the rest of the rows shows the equality or inequality of the constraint equations to be defined. In the last column, right amount of the constraint equations be seen representing the value of the land surface area. The results showed Lingo software optimization solution for all three options examined included the status quo, the situation with land management and standard conditions, the optimal level of land use that could minimize erosion and maximize revenue will be as Table 5. Using table 5, the calculation of soil erosion and profit before and after land use optimization was done that for example the current situation of land uses is presented in Tables 6 and 7. So, the values obtained for the three land use options of current status options, land management and standard status were compared that the results are showed in Tables 8 and 9. The amounts of increase profitability and reduce erosion resulting after optimizing has been shown in Tables 10 and 11 are provided.

Results of the Table 10 showed that if land use optimized, net profit rate of 3.68% of the land in its current state, 21.39% in the status of land management and 24.20% in standard conditions will increase. Similarly, the results presented in Table 11 shows that with land use optimization, 0.75% erosion in its current state, 42.27% in the status of land management and 60.95% under standard conditions will reduce.

Table 5. Area of land uses in both of optimal and non-optimal state

Allocated area (ha)		Land use type
After Optimization	Before Optimization	
507	408	Horticulture
2283	2283	Range
136	169	Irrigated Farm
570	636	Dry farming

Table 6. Calculation of profit and erosion in the current status of Qushchi watershed

Total net Income (Euro/ year)	Net Income (Euro/ha/ year)	Total erosion (ton/ year)	Annual erosion (ton/ha)	Area (ha)	Land use
78601.50	192.65	3264	8	408	Horticulture
230963.69	101.17	31962	14	2283	Range
9303.58	55.05	1690	10	169	Irrigated Farm
39177.90	61.60	7632	12	636	Dry farming

Table 7. Profit and erosion of the current status of land use optimization model in Qushchi watershed

Total net Income (Euro/ year)	Net Income (Euro/ha/ year)	Total erosion (ton/ year)	Annual erosion (ton/ha)	Area (ha)	Land use
97673.92	192.65	4056	8	507	Horticulture
230963.69	101.17	31962	14	2283	Range
7486.91	55.05	1360	10	136	Irrigated Farm
35112.27	61.60	6840	12	570	Dry farming

Table 8. Comparison of erosion before and after optimization of land use options (tons per year)

Standard setting		Land management practices		Current status		Land use
After Optimization	Before Optimization	After Optimization	Before optimization	After Optimization	Before Optimization	
2028	2028	2535	2040	4056	3264	Horticulture
20547	20547	22830	22830	31960	31962	Range
544	544	816	1014	1360	1690	Irrigated Farm
4560	4640	5130	5724	6840	7632	Dry farming
27679	27759	31311	31608	44218	44548	Total

Table 9. Comparison of annual profits before and after optimization of land use options (Euro per year)

Standard setting		Land management practices		Current status		Land use
After Optimization	Before Optimization	After Optimization	Before optimization	After Optimization	Before Optimization	
233817.44	233817.44	233817.44	233817.44	230963.69	230963.69	Horticulture
14763.26	14763.26	11226.91	13951.08	7486.91	9303.58	Range
47764.02	46940.50	41240.50	46015.71	35112.27	39177.90	Irrigated Farm
443895.11	443895.11	434658.76	413185.73	371236.78	358046.67	Dry farming
233817.44	233817.44	233817.44	233817.44	230963.69	230963.69	Total

Table 10. Changes in total net profit after optimization of the land use in relation to different options

After Optimization						Before optimization
Standard setting		Land management practices		Current status		Current status
Increase (%)	Amount (Euro/ year)	Increase (%)	Amount (Euro/ year)	Increase (%)	Amount (Euro/ year)	
24.20	443895.11	21.39	434658.76	3.68	371236.78	358046.67

Table 11. Erosion rate changes after land use optimizing changes in relation to different options

After Optimization						Before Optimization
Standard setting		Land management practices		Current status		current status
Increase (%)	Amount (Euro/year)	Increase (%)	Amount (Euro/year)	Increase (%)	Amount (Euro/year)	
60.95	0.69	42.27	0.78	0.75	1.11	1.11

Using sensitivity analysis of changes compared to the optimization, critical factors were identified that some of their results in the current situation is shown in the Figures 3, 4 and 5 for example.

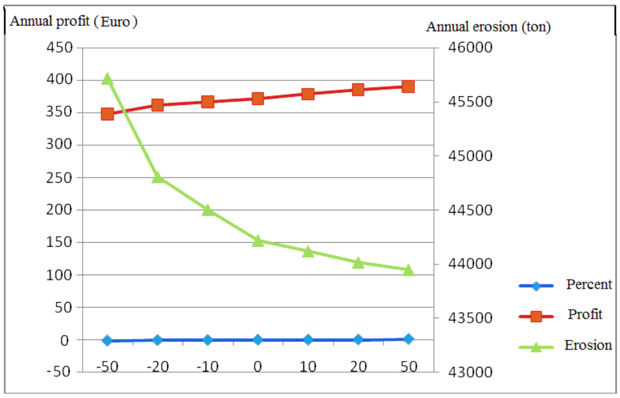

Figure 3. Sensitivity analysis of objective functions in relation to the highest area of horticultural land in current status

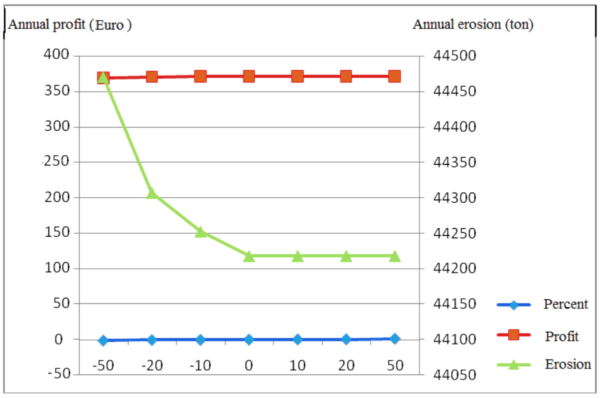

Figure 4. Sensitivity analysis of objective functions in relation to the highest area of irrigated farms in current status

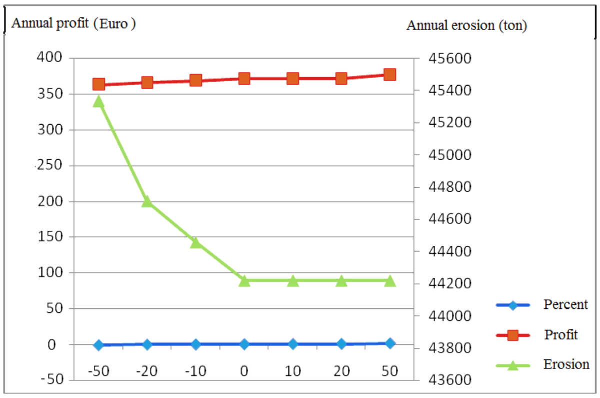

Figure 4. Sensitivity analysis of objective functions ratio to the highest area of irrigated farms and horticulture in current status

Discussion

In this research, we used linear programming to optimize land uses that match with the findings of (Liu and Stewart, 2004) but (Benli and Kodal, 2003) have emphasized on non-linear programming to maximize profits for the agricultural land use. Our results showed that with optimizing land use, erosion rates can be reduced about 61%. Erosion reduce can be due to reduction of the irrigated and rainfed land surface area and increasing the surface area of garden. It also has about 24% the profitability area has been added compared to the before optimizing situation. These results are consistent with the results of previous studies (Jalili, 2004; Nikkami et al., 2002; Singh and Singh, 1999). Results of the sensitivity analysis showed that the change in the surface area of garden and rangeland has the greatest impact on the profitability and erosion rate.

Conclusion

The results of this research showed that the current state of land use in the Qushchi watershed is not suitable to minimize soil erosion because erosion rates only 0.75% reduced after the land use optimization without land management. So it is necessary to optimize land use management practices. It can also reduce soil erosion and increase of the resident income by managing the different land uses. Changes in the garden and range land have the greatest impact on increasing profitability and reducing erosion. Water supply for this change is an important issue that can be provided by watershed management like construction of small water reservior dams and new sprinkler and drip irrigation methods. The animal population dependent on range is six times of the range capacity that led to its destruction and increase erosion. Therefore, it is recommended using Education and Extension to promote the importance of land management and to understand how proper use of the land to the villagers that improper management of land use in a watershed has a disproportionate impact on available resources. Land use optimization is one of the strategies for achieving sustainable development and protection of the soil.

References

Benli, B., Kodal, S., 2003. A non-linear model for farm optimization with adequate and limited water supplies: Application to the South-east Anatolian Project (GAP) Region. *Agricultural Water Management* 62(3): 187–203.

Ferreira, V., Panagopoulos, T., Cakula, A., Andrade, R., Arvela. A., 2015. Predicting soil erosion after land use changes for irrigating agriculture in a large reservoir of Southern Portugal. *Agriculture and Agricultural Science Procedia* 4: 40-49.

Flah-Shamsi, R., 2004. Economic assessment of different applications in the Middle Kalaybar-chay Watershed (North Arasbaran) using linear programming and GIS. Tehran University, Faculty of Forestry, Natural Resources, Iran. PhD thesis. 331 p. [in Persian]

Gholami, M., 2003. Determination of the optimal crop rotation using linear programming (case study farm of 110 ha in Bojnoord). *Iranian Journal of Agricultural Sciences and Natural Resources* 10 (1): 17-24 [in Persian].

Jalili, Kh., 2004. Optimization land use of watershed to minimize soil erosion using linear programming. Tarbiat Modarres University. Department of Watershed Management of Natural Resources, Iran. MSc thesis 87 p. [in Persian].

Li, L., Wang, Y., Liu, C., 2013. Effects of land use changes on soil erosion in a fast developing area. *International Journal of Environmental Science and Technology* 11(6): 1549-1562.

Liu, D., Stewart, T.J., 2004. Object-oriented decision support system modeling for multicriteria decision making natural resource management. *Computer and Operation Research* 31(7): 985-999.

Mohseny Saravi, M., Farzanegan, M., Koopayee, M., Kholgi, M., 2001. Determination of optimal utilization of resources of watersheds using goal programming. *Iranian Journal of Natural Resources* 56 (1 & 2): 3-16 [in Persian].

Nikkami, D. Elektorowicz, M., Mehuys, G.R., 2002. Optimizing the management of soil erosion. *Water Quality Research Journal of Canada* 37(3): 577-586.

Pasour, E.C., 1983. Land use planning: Implications of the economic calculation debate. *The Journal of Libertarian Studies* 7 (1): 127-139.

Pfaff, A.S.P., Sanchez-Azofeifa, G.A., 2004. Deforestation pressure and biological reserve planning: a conceptual approach and an illustrative application for Costa Rica. *Resource and Energy Economics* 26(2):237–254.

Riedel, C., 2003. Optimizing land use planning for mountainous regions using LP and GIS towards sustainability. *Indian Journal of Soil Conservation* 34(1): 121-124.

Rounsevell, M.D.A., Annetts, J.E., Audsley, E., Mayr, T., Reginster, I., 2003. Modelling the spatial distribution of agricultural land use at the regional scale. *Agriculture, Ecosystem and Environment* 95(2-3): 465-479.

Shively, G., Coxhead, I., 2004. Conducting economic policy analysis at a landscape scale: examples from a Philippine watershed. *Agriculture, Ecosystem and Environment* 104(1): 159-170.

Singh, A., 2016. Optimal allocation of resources for increasing farm revenue under hydrological uncertainty. *Water Resources Management* 30(7): 2569–2580.

Singh, A.K., Singh J.P., 1999. Production and benefit maximization through optimal crop planning: A case study of Mahi Command. *Indian Journal of Soil Conservation* 27(2):157-152.

Tra, N.T., Egashira, K., 2004. Land use effectiveness by farm households after land and forest allocation at Tran Yen district, Yen Bai province. *Journal of the Faculty of Agriculture Kyushu University* 49(2): 461-466.

Wang, X.H., Yu, S., Huang, G.H., 2004. Land allocation based on integrated GIS-optimization modeling at a watershed level. *Landscape and Urban Planning* 66 (2): 61-74.

Yueqing, X., Luo, D., Peng. J., 2011. Land use change and soil erosion in the Maotiao River watershed of Guizhou Province. *Journal of Geographical Sciences* 21: 1138.