

Evaluation of Land Use to Decrease Soil Erosion and Increase Income

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Abstract

Land use optimization is one of the most important issues that has a big effect on soil conservation. In this project in order to achieve minimum soil erosion and maximum profit of different land uses, including forest, orchard, range, irrigated and dry farming land use, linear programming was used in Qazvin plain watershed. Three different scenarios of land use were designed: 1) existing land use, 2) existing land use with some land management, and 3) optimum land use with suitable land management. By using Lingo software, the optimum statuses were determined. The results showed that the area of orchards (45% increased), irrigated lands (58% decreased), and dry lands (53% decreased) have to be changed for optimization land uses, but the area of forest and rangeland did not need any changes. Also, the amount of soil erosion in existing land use, existing land use with land management, and optimum land use with suitable land management declined 4%, 30%, and 39%, respectively, while their profit increased 30%, 39%, and 40%, respectively. In addition, the results of sensitive analysis indicated that orchard and irrigated land are the most sensitive land uses in solving the problem.

Keywords: erosion, income, land use, optimization

Introduction

Soil erosion as one of the major threats of the environment causes economic problems, especially when human activities increase. Improper land use is one of the important factors causing soil erosion, and it has been shown that double drilling declines soil loss through concentrated flow by 25% on average and by up to 40% under optimal conditions [1]. Other research found that pasture heavily declines organic C, total N, and cation exchange capacity by 33, 28, and 18 percentages, respectively. Also, they showed that changing range to cultivation caused soil loss decrease until 92 percentages [2]. Also, changing land use from forest to cultivation has significant effect on soil loss [3]. Investigating relationships between land use and soil erosion in Malaysia indicated that soil loss in range with

heavy grazing was 22.28 g, while soil loss in land without grazing was 15 g [4].

This subject has good impact on the development of some models for estimating minimum soil erosion and maximum profit of different land uses. Finding a solution for minimizing soil erosion via land use is very important in watershed management. Optimizing land use by using a management program is a useful tool in order to decrease soil erosion. For investing the optimum of different factors such as type of land use, water amount, and income in order to decrease sediment and erosion, the linear and non-linear programs could be used. Related to this, some researchers evaluated soil erosion, net benefit, and land use capability map with ADBASE software and, finally, sensitivity analysis conducted to determine more effective land use in reducing soil erosion and increasing benefit. Their results showed that soil erosion and benefit could reduce and increase by 7.9 and 18.6 percentages, respectively.

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The model was sensitive to irrigated farming and orchard areas [5]. In addition, Land use optimization in Orazan sub-basin, Iran, showed an increase in net income by 22.24% and a decrease in erosion net by 6.93% [6].

In this project in order to achieve minimum soil erosion and maximum profit of different land uses, including forest, orchard, range, and irrigated and dry farmland, we used linear programming in Qazvin plain watershed, Iran.

Materials and Methods

Study Area

The study area is located in Qazvin Plain (between 49°25'–50°35'E and 35°25'–36°25'N) in the center of Iran (Fig. 1). This region is characterized by a minimum and maximum height of 892 and 1,000 m above sea level, respectively, in an area of 450,000 ha. Also, the soil moisture and temperature regimes are Aridic and Thermic, respectively. The major land uses in this area are irrigated and dry farming land uses, range, and orchard by areas of 22, 17, 45, 0.004 percentages, respectively.

At first, different studies including physiography, soil science, erosion and sediment, geography, plant cover, hydrology, and economic and social studies of Qazvin were collected. Sediment yield in each land use was calculated by MPSIAC (Modified Pacific South West Inter-Agency Committee). Amount of yield erosion for every land use was determined via sediment delivery ratio (SDR). In addition, soil erosion was estimated by EPM model.

The data of benefit and net income of productions for every land use by filling asking forms were completed. In order to minimize soil erosion and maximize income for residents of the study area, some functions were used and finally the optimal land uses were determined.

The basic aim of this research was to gain the purpose of land use optimization. The meaning of land use optimization is maximum profit and minimum soil erosion. Maximizing profit is:

$$\text{Max } (Z_1) = \Sigma[(A_{i1}+A_{i2})]X_i \quad (1)$$

...where Z_1 is the annual net profit based on one million Iranian Riyals per year ($\text{mIR}\cdot\text{y}^{-1}$), A_{i1} is the gross profit for each land use, A_{i2} is the product costs spent on each land use, A_{i3} is the cost wasted on soil caused by erosion in each land use, and X_i is the area of each land use (ha).

Another objective is minimizing soil erosion that was assayed by the following equation:

$$\text{Min } (Z_2) = \Sigma C_{Ei}X_i \quad (2)$$

...where Z_2 is soil erosion ($\text{ton}\cdot\text{y}^{-1}$), C_{Ei} is annual soil erosion for each land use ($\text{ton}\cdot\text{ha}^{-1}\cdot\text{y}^{-1}$), X_i is the area of each land use (ha), i and n are the number and total number of each land use, respectively.

In this stage some linear equations were used. These relationships could be written for maximizing net income for every five land uses, including forest, rangeland, orchard, and irrigated and dry lands. The totally relationship is:

$$\text{Max } (Z_1) = C_{B1}X_1 + C_{B2}X_2 + C_{B3}X_3 + C_{B4}X_4 + C_{B5}X_5 \quad (3)$$

...where Z_1 is annual net income of the watershed ($\text{mIR}\cdot\text{y}^{-1}$), C_{B1} , C_{B2} , C_{B3} , C_{B4} , and C_{B5} are annual net profit of forest, rangeland, orchard, irrigated and dry lands ($\text{mIR}\cdot\text{ha}^{-1}$), respectively. X_1 , X_2 , X_3 , X_4 , and X_5 are the area of forest, rangeland, orchard, irrigated and dry lands, respectively.

In order to minimizing soil erosion the following equation was used.

$$\text{Min } (Z_2) = C_{E1}X_1 + C_{E2}X_2 + C_{E3}X_3 + C_{E4}X_4 + C_{E5}X_5 \quad (4)$$

...where, Z_2 is annual erosion of whole watershed, C_{E1} , C_{E2} , C_{E3} , C_{E4} , and C_{E5} are soil erosion of forest, rangeland, orchard, irrigated and dry lands ($\text{ton}\cdot\text{ha}^{-1}\cdot\text{y}^{-1}$), respectively. X_1 , X_2 , X_3 , X_4 , and X_5 are the area of forest, rangeland, orchard, irrigated and dry lands, respectively.

Also, in order to determine critical parameters, sensitivity analysis was used.

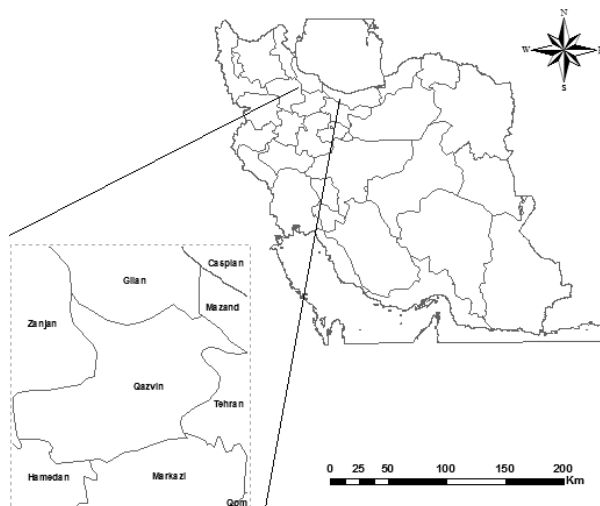


Fig. 1. Map of study area.

Table 1. Simplex table of land use optimization in scenario 1.

Functions	X ₁ (forest)	X ₂ (rangeland)	X ₃ (orchard)	X ₄ (irrigated land)	X ₅ (dry land)	Modality	Right hand side of equation
Function 1	1.65	0.43	85.83	10.48	0.495	Max	0.00
Function 2	-10.18	-11.94	-7.76	-15.60	-16.55	Max	0.00
Constraint 1	1.00	0.00	0.00	0.00	0.00	≤	10,807
Constraint 2	0.00	1.00	0.00	0.00	0.00	≤	10,811
Constraint 3	0.00	0.00	1.00	0.00	0.00	≤	574
Constraint 4	0.00	0.00	0.00	1.00	0.00	≤	1,279
Constraint 5	0.00	0.00	0.00	0.00	1.00	≤	720
Constraint 6	1.00	1.00	1.00	1.00	1.00	≤	238
Constraint 7	1.00	1.00	1.00	1.00	1.00	≥	1,999
Constraint 8	0.00	0.00	1.00	0.00	0.00	≥	23,733

Table 2. Simplex table of land use optimization in scenario 2.

Functions	X ₁ (forest)	X ₂ (rangeland)	X ₃ (orchard)	X ₄ (irrigated land)	X ₅ (dry land)	Modality	Right hand side of equation
Function 1	1.99	0.61	104	11.97	1.07	Max	0.00
Function 2	-6.87	-8.03	-4.16	-8.61	-8.75	Max	0.00
Constraint 1	1.00	0.00	0.00	0.00	0.00	≤	10,807
Constraint 2	0.00	1.00	0.00	0.00	0.00	≤	10,811
Constraint 3	0.00	0.00	1.00	0.00	0.00	≤	574
Constraint 4	0.00	0.00	0.00	1.00	0.00	≤	1,279
Constraint 5	0.00	0.00	0.00	0.00	1.00	≤	720
Constraint 6	1.00	1.00	1.00	1.00	1.00	≤	238
Constraint 7	1.00	1.00	1.00	1.00	1.00	≥	1,999
Constraint 8	0.00	0.00	1.00	0.00	0.00	≥	23,733

Results and Discussion

The objective function of the soil loss minimization problems and maximization of profit for scenario 1 was formulated according to equations 5, 6.

$$\text{Max } (Z_1) = 1.65X_1 + 0.43X_2 + 85.83X_3 + 10.48X_4 + 0.45X_5 \quad (5)$$

$$\text{Min } (Z_2) = -10.18X_1 - 11.94X_2 - 7.76X_3 - 15.60X_4 - 16.55X_5 \quad (6)$$

...where Z₁ is annual net profit (mIR·y⁻¹), Z₂ is total soil erosion (t·y⁻¹), and X₁, X₂, X₃, X₄, and X₅ are areas of forest, rangeland, orchard, irrigated land and dry land (ha), respectively.

Also, for scenario 2 the objective function was determined according to equations 7 and 8 and for scenario 3 in equations 9 and 10.

$$\text{Max } (Z_1) = 1.99X_1 + 0.61X_2 + 104X_3 + 11.97X_4 + 1.07X_5 \quad (7)$$

$$\text{Min } (Z_2) = -6.87X_1 - 8.03X_2 - 4.16X_3 - 8.61X_4 - 8.75X_5 \quad (8)$$

$$\text{Max } (Z_1) = 5.74X_1 + 6.40X_2 + 3.40X_3 + 6.85X_4 + 7.33X_5 \quad (9)$$

$$\text{Min } (Z_2) = -5.74X_1 - 6.40X_2 - 3.40X_3 - 6.85X_4 - 7.33X_5 \quad (10)$$

There are some limitations for solving these land use optimizing equations in this study area (Tables 1 to 3). The minimum area of an orchard cannot be less than 574 ha (X₃ ≥ 574). Residents of this watershed do not have any tendency to decrease this area.

In addition, the area of orchard in the current situation is 574 ha, but it could be increased to 1,279 ha. Because the land with slope more than 5% and optimum land depth can be allocated to an orchard (X₂ ≤ 1279).

Also, forest and rangeland should not consider less than 10,807 (X₃ ≥ 10,807) and 10,811 ha (X₄ ≥ 10,811), respectively. Forest and rangeland are national resources and we cannot alter these areas.

Table 3. Simplex table of land use optimization in scenario 3.

Functions	X_1 (forest)	X_2 (rangeland)	X_3 (orchard)	X_4 (irrigated land)	X_5 (dry land)	Modality	Right hand side of equation
Function 1	1.99	0.61	115	14.16	1.39	Max	0.00
Function 2	-5.74	-6.40	-3.40	-6.85	-7.33	Max	0.00
Constraint 1	1.00	0.00	0.00	0.00	0.00	\geq	11512
Constraint 2	0.00	1.00	0.00	0.00	0.00	\geq	10758
Constraint 3	0.00	0.00	1.00	0.00	0.00	\leq	574
Constraint 4	0.00	0.00	0.00	1.00	0.00	\leq	363
Constraint 5	0.00	0.00	0.00	0.00	1.00	\geq	115
Constraint 6	1.00	1.00	1.00	1.00	1.00	\geq	0
Constraint 7	1.00	1.00	1.00	1.00	1.00	\leq	1279
Constraint 8	0.00	0.00	1.00	0.00	0.00	\leq	400

The minimum area for irrigated farmland is 1,279 ha ($X_5 \geq 1,279$). Watershed residents are supplied with products of irrigated farmland, including seed for next cultivation. Therefore, the area of irrigated farmland does not have to be less than 1,279 ha. The minimum area of dry farmland is 720 ha ($X_6 \geq 720$). Similar to irrigated farmland, the area of dry farmland cannot decrease.

The next constraint is the positive value of the areas ($X_1, X_2, X_3, X_4, X_5 > 0$).

According to a standard situation for irrigated cultivation such as soil depth and available water, only 400 ha lands are suitable. So, area was decreased from 1,279 to 400 ha ($X_6 \leq 400$).

Since slopes more than 12% are not suitable for dry farming, after evaluation of slope and depth of the soil, the area of 330 ha of dry farming was decreased to 264 ha ($X_7 \leq 264$).

The final limitation is that the summation of the area of the five land uses must equal 23,733 ha.

Simplex method tables were prepared in order to solve functions and achieve the best combination of land uses. According to Table 4, the area of land use including orchard, and irrigated and dry farms changed from 574 to 1,279 ha (55% decrease), from 1,211 to 363 ha (70% decrease), and

Table 4. Results of land use optimization in scenario 1.

Land Use	Allocated area before optimization (ha)	Allocated area after optimization (ha)
Forestland	10,807	1,164
Rangeland	10,811	10,661
Orchard	574	1,279
Irrigated farming	1,211	363
Dry farming	330	264

from 330 to 115 ha (64% decrease), respectively. There is not any change in areas of forest and rangeland. In this relationship, some researchers show that the optimum situation changed land use area. The orchard area increased from 561 to 2118 ha, irrigated farming decreased from 871 to 237 ha, and dryland decreased from 1,049 to 207 ha [7]. In addition, optimization land uses by Nikkami indicated increasing orchard area by 3.5% and declining dryland by 100% [8].

Also, the amount of erosion before optimization was 321,563 $\text{ton}\cdot\text{y}^{-1}$ and in scenarios 1, 2, and 3 it decreased to 307,851, 204,773, and 169,519 $\text{ton}\cdot\text{y}^{-1}$ (Tables 5, 6, and 7). In addition, the amount of profit before optimization of land use was 106,334 mIR and after that it increased to 168,242 mIR, so the profit of study area increased 36%. Land use optimization in England was shown to rise at income to 18.62% and a decline in soil erosion to 7.87% [9].

The results of sensitivity analysis showed that reduction the area of orchard and irrigated farms increased soil loss. There is a direct relationship between soil loss and variation in orchard and irrigated lands. Results of sensitivity analysis in Jajrood watershed of Iran indicated that increasing in area of rangeland and the decline in summation of orchard and irrigated farming cause a drop in profit [10]. Also, there is a direct relationship between the area of orchard and irrigated land and amount of profit. But with decreasing orchards soil erosion increased, because dry land with high slope could be substituted with orchard that caused soil erosion.

Conclusion

One of the solutions for declining soil erosion is raising the orchard lands that have high incomes. The development of summation area of irrigated lands and rangelands can dramatically increase soil erosion, while dropping in area of orchard and irrigated lands increases soil erosion because of expansion of rangeland.

Table 5. Results of land use optimization in scenario 1.

Land Use	Allocated area (ha)	Erosion rate (ton·ha ⁻¹ ·y ⁻¹)	Total erosion (ton·y ⁻¹)
Forestland	10,807	10.18	132,075
Rangeland	10,811	11.94	154,940
Orchard	574	7.6	5,265
Irrigated farming	1,211	15.60	22,695
Dry farming	330	16.55	6,584
Total	23,738	-	321,563

Table 6. Results of land use optimization in scenario 2.

Land Use	Allocated area (ha)	Erosion rate (ton·ha ⁻¹ ·y ⁻¹)	Total erosion (ton·y ⁻¹)
Forestland	1,164	6.87	96,060
Rangeland	10,661	8.03	104,230
Orchard	1,279	4.16	6,398
Irrigated farming	363	8.61	3,758
Dry farming	115	8.75	1,218
Total	24,215	-	211,667

Table 7. Results of land use optimization in scenario 3.

Land Use	Allocated area (ha)	Erosion rate (ton·ha ⁻¹ ·y ⁻¹)	Total erosion (ton·y ⁻¹)
Forestland	11,922	5.74	82,150
Rangeland	10,347	6.40	79,574
Orchard	1,279	3.40	523
Irrigated farming	400	6.85	3,293
Dry farming	264	7.33	7.33
Total	24,215	-	172,580

The results of this research show that it can be helpful for selecting optimum land use of every watershed by improving the economic statue and reaching sustainable environment.

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