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Analysis of vegetation-based management scenarios using MCDM in the Ramian watershed, Golestan, Iran

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Abstract

This research has concentrated on the physical and socio-economic impacts of vegetation-based management scenarios targeting on flooding and soil erosion issues in the Ramian watersheds. The Ramian watershed with an approximate area of 24000 ha is located in Golestan, Iran. For each sub-watershed, four biological actions (activities) and 16 management scenarios have been considered. Physical impacts were studied using the SCS (Soil Conservation Service) hydrologic model and the EPM (Erosion Potential Method) model. Economic and social impacts have been evaluated using the cost/benefit analysis and the examination of the results of a social survey, respectively. Some physical, social, and economic indices were chosen and quantified. The indices then were standardised using the interval standardisation technique. Best scenarios were determined using a Multiple-Criteria Decision Making (MCDM) technique. To weight the indices, four perspectives were used. For the first three perspectives one of the physical, social and economic criteria were assigned higher weights while for the fourth perspective all criteria were given equal weights. Trade-off analysis of the results indicates that for most sub-watersheds more than one single management solution can be recommended on the basis of the different perspectives. The results showed that the multiple-criteria decision making serves as a valuable tool to represent the watershed system as a whole, to incorporate output from models and expert-judgments to examine the trade-offs among outcomes necessary to decision making.

Keywords: Integrated watershed management; Multiple-criteria decision making; The Ramian watershed; Vegetation-based scenarios

Introduction

Globally and particularly in developing countries, population growth and increasing demands for food and other goods resulted in inappropriate use of soil and water resources. Conversions of upland forest areas into croplands have lead to accelerated soil degradation and the depletion of soil productivity. Flooding, water pollution, and socio-economic welfare problems are the other negative consequences of inappropriate use of soil and water resources. The complexity of natural resource management is echoed in the integrated assessment and management-related literature (see for example Heathcote, 1998; Letcher, 2002; Pollard, 2002; Jakeman and Letcher, 2003). Watersheds are living ecosystems, consisting of interlinked webs of land, water, biota, and people (Pollard, 2002). Watersheds are natural integrators of stream flow and, as a result, of human impacts (Ames, 2002). Using watersheds as management units allows managers to devise a holistic view of interconnected components of an area, the watershed (Pollard, 2002). Integrated watershed management is globally accepted as a sound approach for management of water, land, and related resources which takes care of equilibrium between socio-economic demands of watershed inhabitants and ecosystem sustainability. Through implementing an integrated watershed management approach all major factors and events influencing water resources are taken into consideration (Pollard, 2002). Considering the nature of watersheds as a specific class of management systems, integrated watershed management provides a framework for integrating knowledge and perspectives of the social, economic, and natural sciences into planning, policy and decision-making (Fulcher et al., 1997). Decisions made in the area of watershed management must be defensible, while simultaneously considering response and feedback mechanisms among different components of the system, accounting for biophysical, social, and economic considerations and resolving conflicts among the special interests of user groups of the resources in the watershed system (Mowrer, 1997). Synthesis of problems, driving factors, biophysical and socio-economic perspectives, watershed-dependent communities, data and models of different scales are elements of integrated watershed assessment and management (Jakeman et al., 2005). Detailed understanding and trade-off analysis of results from implementation of different management scenarios at various spatial and temporal scales will improve decision making. Sadoddin et al. (2003) using the Bayesian decision networks studied the socio-economic and biophysical impacts of biological scenarios for salinity management in Australia and presented the best management scenarios. Their results showed that the Bayesian decision network serves as a valuable tool to represent the watershed system as whole, to incorporate output from models and expert judgments to examine the trade-offs among outcomes necessary for decision making and to communicate uncertainty of the parameters. Al-weshah and El-Khoury (1999) conducted a regional flood analysis using WMS (Watershed Modelling System) model in Jordan and compared three scenarios of forestation, terracing and check-dams construction. They concluded that the forestation is the best scenario which leads to peak discharge reduction as well as total volume discharge reduction up to 70 percent. The main aim of this study is to develop and demonstrate an approach which is used for integrated management of watersheds.

Material and Methods

Study area

The Ramian watershed, a sub-basin of the Gorganrood River basin, is located in the eastern part of the Golestan province, Iran. It has an area of about 240 km^2 and the geographic position lies between 55^o 02’- 55^o 18’ E longitudes and 36^o 49’- 37^o 02’ N latitudes. Elevation ranges from 220 to 2890 m MSL.

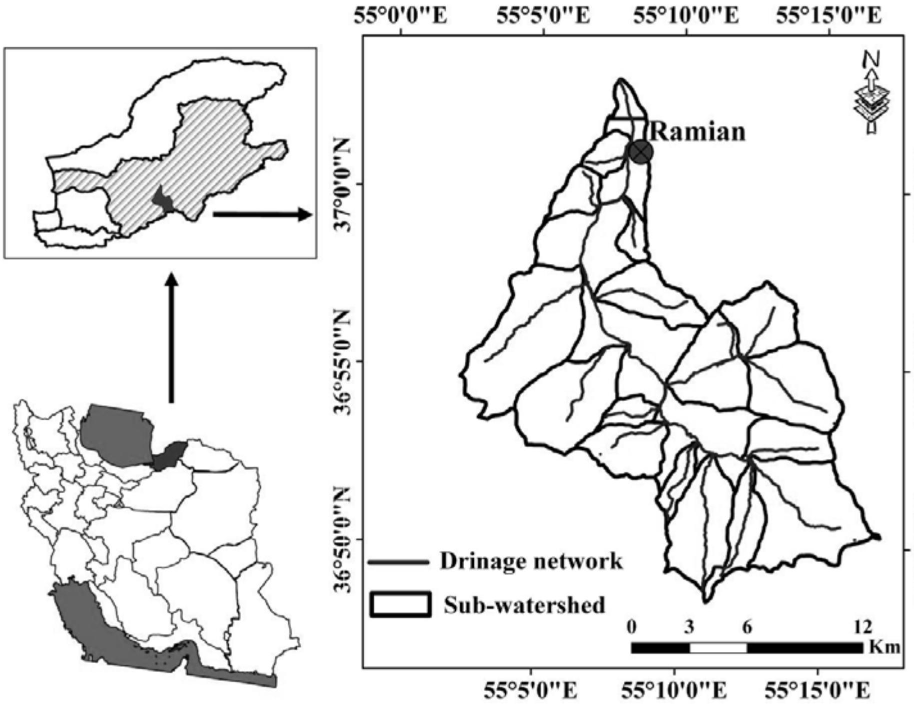

Figure 1. Location of the Ramian watershed in Golestan Province, Iran.

Forest is the dominant land cover type in the watershed. However, like most of the Caspian Hyrcanian mixed forest ecoregion, extensive logging and clearing of forests for agriculture are nearly eliminating the forests in this area (Heshmati, 2007). Mean annual precipitation is 898 mm and mean daily temperature is 16.5 ^{o}C. According to the de Martonne and Emberger classifications the climate of the study area is humid and cold humid, respectively (Tajiki, 2007). The Ramian town with an approximate population of 80,000 is located in the immediate downstream of the watershed's outlet. Considering the high flooding susceptibility of the watershed and socio-economic importance of areas exposed to inundation, flood mitigation measures are necessary to be planned and implemented. Furthermore, the susceptible geological formations, water erosion, intense road construction and land use conversion from forests to croplands in some steep areas have lead to on-site soil degradation and off-site sedimentation in downstream (Shomal Consulting Engineering Inc., 2007). In order to cease the depletion of watershed resources such as soil, water and plant, in this study a scenario-based approach has been used to predict the impacts of different management activities within an integrated watershed management framework. In addition, a trade-off analysis of the results has been carried out to provide a proper basis for decision making.

Methodology

Watershed management using scenario analysis approach

Contrary to mathematical optimization models, scenario-based approaches increase the insight of watershed inhabitants regarding watershed system (Cain, 2001). Scenario-based approaches allow the users to choose different management scenarios and evaluate their possible positive and/or negative outcomes. Using a scenario-based approach in this study is consistent with the intention of supporting decision makers rather than making decision for them (Cain, 2001). This procedure improves our knowledge about watershed system and its behavior and helps to identify the best management scenario.

Conceptual model for integrated management of the Ramian watershed

In this study a conceptual model representing the cause and effect relationships between variables and comparing the impacts of management scenarios on biophysical and socio-economic characteristics of the watershed system have been integrated (Figure 2).

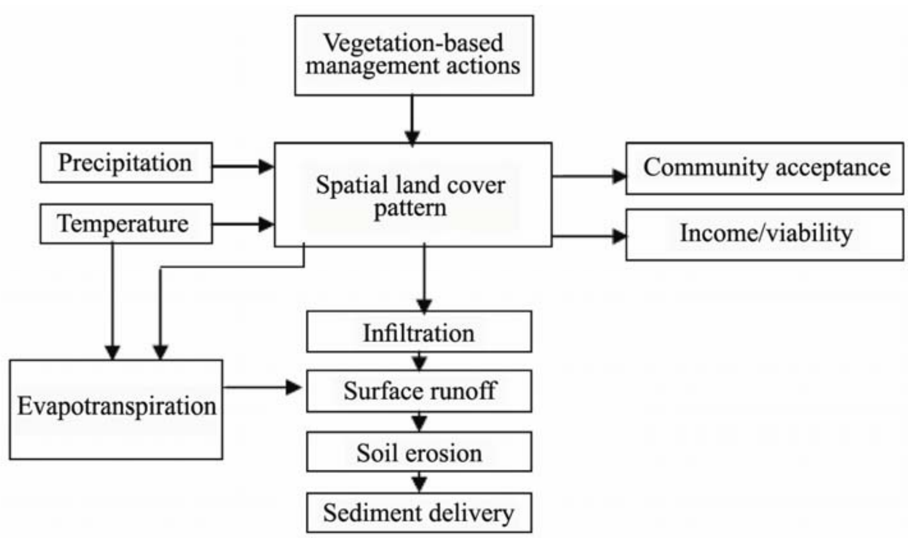

Figure 2. The conceptual model framework for vegetation-based management of the Ramian watershed.

Developing of mutually exclusive vegetation-based management scenarios

First the sources of surface runoff and sediment problems over the Ramian watershed system and their relative importance are identified. Then a list of all feasible solutions for mitigation or elimination of these problems is prepared. Maintaining the current condition can sometimes be a solution for a watershed to recover itself through natural evolution particularly once the watershed disturbance is not extended in a large scale (Heathcote, 1998). Furthermore it can be used as a base case scenario to evaluate the other scenarios. After identifying the contemporary management activities in the study area, the possible management actions were defined considering the existing constraints in the watershed. For the Ramian watershed four biological actions were considered including: agro-forestry, tree plantation, seeding, and sowing. Combination of these four actions leads to 16 (2^n) different management scenarios (Table 1).

Table 1. Vegetation-based management scenarios for the Ramian watershed

Scenario	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Agro-forestry	-	+	-	-	-	+	-	-	+	+	-	+	-	+	+	+
Seeding	-	-	+	-	-	+	+	-	-	-	+	+	+	+	-	+
Sowing	-	-	-	+	-	-	+	+	+	-	-	+	+	-	+	+
Tree planting	-	-	-	-	+	-	-	+	-	+	+	-	+	+	+	+

+ Sign indicates the presence, and - Sign indicates the absence.

It should be mentioned that the management scenarios should be exclusive. In other words, admission of one scenario leads to refusal of other scenarios. Regarding the fact that most croplands of the study area are cultivated with wheat and there is a tendency among the watershed community for establishing fruit trees, a walnut-wheat agro-forestry system has been proposed as an action.

Input map layers including sub-watersheds boundary, hypsometry, slope, vegetation cover type and density, soil depth, and hydrologic soil groups were prepared and superimposed within the ArcGIS environment in order to specify the spatial distribution of various management activities considering the scenario development rules shown in Table 3. In developing the scenarios, 100% of suitable areas for each vegetation-based activity have been allocated for it.

Table 2. Scenario rules for vegetation-based management of the Ramian watershed.

Biological actions	Suitable areas
Agro-forestry	Croplands with slope less than 40% and semi-deep to deep soils
Tree planting	1) barren lands, shallow soils, low density vegetation, slopes less than 60%, elevations up to 1600 m above MSL 2) forests, semi-deep soils, moderate vegetation density, slope less than 60% elevation up to 1600 m above MSL
Seeding	Forests with semi-deep soils and moderate vegetation density
Sowing	Forests with deep soils and moderate vegetation density, slope more than 60%

Analysis of Integrated Management of the Ramian Watershed

Modelling the physical impacts of vegetation-based scenarios

The SCS model was used to simulate the effects of vegetation cover changes on hydrological characteristics. This method can relate the watershed characteristics to the flow parameters. The Curve Number (CN) is calculated based on hydrologic soil group, antecedent soil moisture condition, and the land use type. The outputs of the model are rainfall excess depth, peak discharge, and time to peak over the watershed with spatial resolution of sub-watershed unit. The initial abstraction and surface runoff depth are calculated with equations 1 and 2, respectively.

$$S = \frac{25400}{CN} - 254 \qquad (1)$$

$$R = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (2)$$

Where, S is initial abstraction in mm; CN is curve number; P is rainfall in mm and R is rainfall excess in mm.
Peak discharge is calculated with equations 3 and 4.

$$Q_p = \frac{2.083AR}{t_p} \qquad (3)$$

$$t_p = \frac{D}{2} + t_l \qquad (4)$$

Where, Q_p is peak discharge in $m^3.s^{-1}$. A is watershed area in ha; R is rainfall excess in mm; t_p is time to peak in hour; D is duration of rainfall excess in hour and t_l is watershed lag time in hour. The 50 years discharge volume for each sub-watershed was calculated by multiplying the 50 years peak discharge and the respective time to peak.
The EPM model has been used to predict the effects of vegetation cover changes on soil erosion rate. The coefficient of erosion (see Equation 5) of the model has been used as a surrogate index of soil erosion rate.

$$Z = Y.X.a.(\Phi + \sqrt{I}) \qquad (5)$$

Where, Y is coefficient of soil resistance to erosion; X is land use coefficient; 'a' is conservation coefficient; Φ is coefficient of the observed erosion process; and I is mean slope of the surface. In order to predict the soil erosion changes in response to each scenario the product of land use coefficient (X) and protection coefficient (a) was calculated and compared with its value at the present condition.

Modelling the economic impacts of vegetation-based management scenarios

Gross margin and variable cost have been used as indices to predict the effects of vegetation cover changes on economic conditions. For each scenario total gross margin is calculated with Equation 6.

$$G = \sum_{i=1}^{n} \left[P_i Y_i - C_i \right] A_i \qquad (6)$$

Where, Y_i is yield of crop *i* (unit of production per unit of area); P is the price of crop (Iranian Rials per unit of production); C is variable costs of crop i (Iranian Rials per unit area); A is the area devoted to crop i (unit area) and n is the number of activities.

To assess the economic impacts of vegetation-based management activities, the decision horizon was considered to be 80 years in order to reflect the time span required for the planted trees to be matured to the stage of industrial harvesting.

Cash flow during 80 years period was translated to the present value. In this study discount rate (the combination of inflation rate and interest rate) was assumed 5%. The documented values in the Biological Study Report of the Ramian watershed along with economic expert-knowledge were utilized to estimate the input parameters.

Modelling the social impacts of vegetation-based management scenarios

The number of stakeholders to be consulted will vary in relations to the scope and breadth of the management questions that will be addressed. A compromise is needed between costs, time, practicality, and diversity and dynamism of stakeholders (Baran and Jantunen, 2004). In a preliminary survey 22 stakeholders inhibited in different parts of the watershed were consulted as a sample of the watershed community to conduct a social survey in order to evaluate the acceptance level of the management scenarios among the community. Social survey participants were enquired about their intentions to implement the vegetation scenarios in the 5 years ahead (starting from, 2006). Analysis of the results of preliminary survey indicated that there is a strong consistency among the opinions of the stakeholders. Therefore it has been assumed that the sample size of 22 stakeholders is satisfactory. The results of the social survey were used to analyze the likely social outcomes of attempt to implement the management scenarios in the watershed. To this end, the binomial probability distribution was used. In the class of the binomial probability experiments, the trials are independent with the probability of acceptance (p) the same for y trial (Harshbarger and Reynolds, 1989). The probability of y successes in n trials is calculated by Equation 7.

$$P(y_i) = \frac{n!}{y_i!(n-y_i)!} p_i^{y_i} q_i^{n-y_i} \qquad (y_i = 0,1,2,...,n) \qquad (7)$$

Where, n is the number of trials (22 participants); P_i is the probability of acceptance (positive answer) of the scenario i in each trial; q_i is probability of non-acceptance (negative answer) of the scenario i in each trial; y_i is the number of acceptance of the scenario i in n trials; $P(y_i)$ is the probability of y_i acceptance in n trials; and i is scenario number (1, 2, …, 16). To analyze the community acceptance towards vegetation-based scenarios, four levels of acceptance (no acceptance, low acceptance, moderate acceptance and high acceptance) were used. The following assumptions were used to assign the level of acceptance. If 2 out of 22 trials were positive, the management scenario was considered to be rejected by the community (no-acceptance), if 3-8 trials were positive, it is considered as low acceptance level, if 9-16 trials were positive, it is considered moderate acceptance level, and if more than 17 trials were positive, it is considered as high acceptance level. Table 3 represents the probability of acceptance of the 16 scenarios. It should be mentioned that p_i is the probability of acceptance identified when financial supports such as subsidies, interest-free loans, and other incentives are provided for improvement of vegetation condition in the watershed.

Table 3. Probability of acceptance of the management scenarios

Scenario	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
Pi	0.45	0.32	0.23	0.23	0.32	0.18	0.33	0.09	0.14	0.18	0.09	0.14	0.14	0.09	0.09	0.09

Multiple-criteria decision making for integrated watershed management

Some researchers attempt to translate all outcomes affiliated to different criteria even the environmental and social ones into the economic outcomes (Heathcode, 1998). However in some circumstances due to shortcomings of this approach, multi-dimensional approach is applied in which all criteria are evaluated separately. In other words, the best scenario is selected considering all criteria collectively. Since criteria are of different nature, they need to be standardised first. This can be done using the interval weighting technique, where each index value is standardised to a range between 0 and 1 and each standardised value is multiplied by its respective weight. The weighted sum then determines the best scenario (Sharifi, 2004). In the interval weighing technique, the indices are categorised into two groups: benefits and costs. Accordingly, equations 8 and/or 9 is used for standardisation purposes (Sharifi, 2004).

For benefit group:

$$index_s = \frac{score - lowest \quad score}{highest \quad score - lowest \quad score} \qquad (8)$$

For cost group:

$$index_s = 1 - \frac{score - lowest \quad score}{highest \quad score - lowest \quad score} \qquad (9)$$

Results

Trade off analysis of the results from implementation management scenarios

As mentioned earlier the indices value corresponding to each management scenario were standardised. Different weights were assigned to the indices based on four different perspectives that might be chosen by the stakeholder in the Ramian watershed (see Table 4).

Table 4. Weights assigned to the indices for different perspectives.

Perspective number	Perspective of weighing	Variable costs	Gross margin	Community acceptance	Soil erosion	Total flood discharge
1	all equal	20	20	20	20	20
2	economic	30	30	20	7.5	12.5
3	social	10	10	60	7.5	12.5
4	physical	10	10	20	25	35

In the next step, the standardized values of indicators were multiplied by their weights and summed up to determine the best scenario (s). Prioritization of scenarios in different weighing perspectives has been shown in tables 5 to 8.

Table 5. List of best management scenarios given equal weights for all criteria.

Preference	Sub1	Sub2	Sub3	Sub4	Sub5	Sub6	Sub7	Sub8	Sub9	Sub10	Sub11	Sub12	Sub13	Sub14	Sub15	Sub16
First	S1	S3	S2	S2	S3	S13	S1	S6	S7	S7	S5	S2	S2	S14	S16	S7
Second	S5	S2	S14	S16	S7	S3	S3	S2	S4	S4	S15	S12	S16	S16	S14	S4
Third	S2	S1	S16	S12	S14	S7	S7	S16	S9	S9	S9	S16	S15	S2	S2	S12

Table 6. List of best management scenarios based on the economic perspective.

Preference	Sub1	Sub2	Sub3	Sub4	Sub5	Sub6	Sub7	Sub8	Sub9	Sub10	Sub11	Sub12	Sub13	Sub14	Sub15	Sub16
First	S1	S2	S2	S2	S3	S3	S1	S2	S7	S7	S9	S2	S2	S2	S2	S1
Second	S2	S1	S3	S9	S7	S7	S3	S6	S6	S4	S2	S12	S12	S12	S12	S7
Third	S7	S13	S12	S12	S6	S6	S7	S12	S11	S9	S1	S5	S9	S6	S6	S4

Table 7. List of best management scenarios based on the social perspective.

Preference	Sub1	Sub2	Sub3	Sub4	Sub5	Sub6	Sub7	Sub8	Sub9	Sub10	Sub11	Sub12	Sub13	Sub14	Sub15	Sub16
First	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1	S1
Second	S5	S2	S2	S2	S2	S2	S2	S2	S5	S5	S5	S2	S2	S2	S5	S2
Third	S2	S5	S5	S5	S5	S5	S3	S5	S7	S7	S2	S5	S5	S5	S2	S5

Table 8. List of best management scenarios based on the physical perspective.

Preference	Sub1	Sub2	Sub3	Sub4	Sub5	Sub6	Sub7	Sub8	Sub9	Sub10	Sub11	Sub12	Sub13	Sub14	Sub15	Sub16
First	S5	S3	S16	S16	S14	S13	S8	S16	S5	S5	S5	S2	S16	S14	S16	S12
Second	S10	S5	S14	S15	S11	S5	S1	S14	S7	S7	S16	S16	S15	S16	S14	S9
Third	S16	S2	S15	S5	S5	S9	S5	S15	S16	S4	S15	S14	S5	S5	S5	S7

Discussion and Conclusions

In using a scenario-based approach for watershed managment, it is necessary to use models which are able to predict the impacts of implementing different scenarios on watershed scale. The results of this study indicate that SCS and EPM models are capable of predicting the impacts of vegetation changes on total discharge and soil erosion rate, respectively. The application of the binomial distribution in the social impact analysis provides a probability distribution function for analysing the community attitudes towards each scenario. By putting emphasis on one of the economic, social, and physical criteria watershed managers and watershed communities choose best scenario(s) in each sub-watershed. In case of encountering a difficulty in identifying a preferred criterion, the best scenario is derived based on the equal weights for all criteria. Trade-off analysis of the results shows that when social criteria are emphasised, in most sub-watersheds scenario 1 gets the highest score followed by scenario 2 (agro-forestry). This indicates that the communities of the Ramian watershed are unwilling to extend forest areas. Choosing criteria depends directly on the national and regional strategies. Therefore, to use the findings of this study, these strategies should be considered. This warranties the feasibility and suitability of the results.

As shown in Tables 8 to 11, for most sub-watersheds more than one unique management solution is recommended given the different perspectives. The approach used in this study allows decision makers and/or stakeholders of the Ramian watershed to reach their own conclusions on the basis of their improved understanding of the system and of the trade-offs among various outcomes arising from implementing management scenarios. This approach is intended to support decision makers in their understanding of trade-offs rather than providing them with a single "optimal" decision. The approach also allows account to be taken of other possible factors not included in the modelling framework for the watershed. This approach occurs with the fact that watershed systems are dynamic and complex and it is a difficult task to capture all of the disciplinary components involved in management of natural resources watershed-wide. To further extend this study and to provide a comprehensive picture of the watershed system ecological criteria can be incorporated in the conceptual modelling framework of this study.

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