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Suitable site selections for gabion check dams construction using analytical hierarchy process and decision making methods

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Abstract

Nowadays, soil erosion and sediment production are one of the problems facing human communities, which lead to less land productivity, low surface water quality, dam reservoir reduction and poor food production Third world and developing countries are not exceptions to this Problem, on the other hand, in these countries because of leakage of financial resources, scientific and meticulous planning is essential to combat problems and to prioritize areas for efficient use of limited resources. Therefore, in this research is an attempt to determine proper location for check dam constructions. Due to information required for decision-making in selecting appropriate regions and due to high intricacy of the effective parameters and high heterogeneity of the area, the spatial analysis in ArcGIS was used for Siazakh basin in Kurdistan province. So that, for determining proper location of check dams, the required basic data, field surveying, maps and other information produced using ARC-GIS, Autodesk-map, ENVI and Expert choice. After that, dendritic model was designed, which, consists of determining hierarchical levels. This hierarchical level contains a set of objects, criteria and Sub criteria. Later, standardization of factors, weighting the criteria and sub criteria was done based on AHP method. Paired test of criteria and sub-criteria (1-9 value) was performed using Expert choice software. Then, quantitative criteria (including: erosion, run off, watershed accessibility and watershed related characteristics criteria) combined with qualitative criteria (socio-economic criteria). Each of these criteria includes sub-criteria. Basin's prioritizing map was produced in GIS by preparation of criteria and sub-criteria map. Waterway map overlaid with prioritizing map and then among 946 waterways, 36 waterways were prioritized and allocated using Expert Choice software.

Key Words: AHP, Check dams, Expert Choice, GIS, Siazakh

Introduction

A watershed is an ideal unit for management of natural resources like land and water and for mitigation of the impact of natural disasters for achieving sustainable development. The significant factors for the planning and development of a watershed are its physiography, drainage, geomorphology, soil, land use/land cover and available water resources. Remote sensing and GIS are the most advanced tools for watershed development, management and studies on prioritization of micro-watersheds for development. Morphometric analysis could be used for prioritization of micro-watersheds by studying different linear and aerial parameters of the watershed even without the availability of soil maps (Biswas et al., 1999).

Suspended sediment load in Siazakh basin based on the recorded data in Nesare Olia station (with upper lands area of about 1056 km^2) was about five tons per hectare from 1999 to 2006. Suspended sediment load trend during these years using linear regression of discharge and sediment was ascending. Thus Morgan in 1986 presented two tons per hectares as a standard amount of soil erosion. (According to this opinion and the fact that there were no dams construction projects done in this basin, in this research decision making technology which was supposed to be the best selection for identifying proper sites). SMCE is powerful software which is suitable for land analyzing (Collins, 2004; Malczewski et al 2001). The recent years compilation of GIS and MCE as a method for determining land suitability and as a result selecting optimized sites for alternative purposes becomes usual practice (Buenrostro Delgado، & et al 2008). It means that MCE is a method in GIS environment for determining and presentation of ways comparing in spatial subjects based on mixing several factors. The output is a map that shows the user every detail about the site. (Malczewski, 2006,). In identifying decision making criteria there is no way but using taskmaster and projects employer's opinions. For selecting the best site there is no need to search for the standards because there is not any. Also, in several fields like commercial management, international communication, political development, corporation subjects and increasingly in management and natural resources it is possible to decide based on opinion (Ianni, 2007; Ramirez, 1999; Nash & et al 2006).

Since the availability of data is increasing and also better methods are developing, presentation of information becomes more complex. Actually in this period, communication and software are developing and help management (Matthies, 2007). These days, new methods that facilitate a more rigorous analysis of multiple criteria have been developed. One sample of application of these methods is ASSESS (a system for best sites selection). AHP and ASSESS are both MCDA methods which are suitable for environmental policy making. It must be mentioned that for evaluating water erosion, regional scale is a proper method to make good decisions. On the other hand, because of reaching to available data and also decreasing quality, limitations are increasing. RS is suitable software for obtaining spatial data for this sort of evaluation. In this research, at first, erosional faces and eroded areas and also evaluation of outdoor effects of erosion like sedimentation and the quality of water that enters the lakes were investigated. In the second step, erosion controlling factors were evaluated. Then, four parameters were studied: topography, soil characteristics, and vegetation cover and management activities. Then erosion map according to satellite images and other information resources was made (Vrieling, 2006). In another study in Kenya a model named SDSS (Spatial Decision Support System to land use planning) was developed, for helping land use experts to classify soil quality, stable evaluation of land management and determining land use potential in suggested land units. Soil quality diagrams and land quality maps were made using the same procedure. This system was suitable for different parts of Kenya (Ochola & Kerkides 2004). Also using both GIS and DSS for determining preferences of nature preservation in ecosystems residuals in an alpine valley was investigated.

In this area, ecosystems were evaluated with ecological morphological indexes. Then, they were classified with MCA (Multi Criteria Analysis). As a result of this evaluation amount of effectiveness of decision making protection technologies for erosion in programming of land use about soil conservation with specified samples was estimated (Geneletti, 2004). In a case study, in Ethiopian Adovai, SDSS and spatial multi criteria analyzes were investigated for removing agricultural sites according to their potential in soil conservation. Applying GIS and IDRISI 3.2 together and editing them and also with direct opinion of land owners, factors and limitations were determined. These practices were based on cover-land use, altitude, erosion potential, closeness to roads and water relation with soil conservation potential of each especial land use. With this program it was predicted that erosion would increase from one ton per hectares per year to 4.5 ton per hectares per year (Dragan & et al 2003). Also, in this study because of having sensitive erosional faces, sediment, erosion and the decreasing volume of under construction dam, Siazakh basin was selected with new method. The validity of an argument is determined when most of the basic studies are done completely and individually and zoning of erosion hazards is introduced as a usual subject, but the step of programming and mixing the information to reduce erosion according to basic studies and reaching to erosion map in a short time with high accuracy using new technologies is a matter that is done in less than any other practices. Some data were gathered by organizations and researching centers. But it is needed to pay more attention to necessary decision makings for reducing hazards with data searching and new methods. On the other hand, programming in a basin is very complex and is possible with interaction between factors and different limitations. So, paying attention to multi criteria analysis technology presents new method in programming and determines proper sites for constructing gabion check and check dams to control erosion. The aim of this paper is using great amount of existing data for multi criteria spatial analysis and decision making technologies in classifying the basin to establish check dams.

Materials and methods

The studied area: Siazakh dam basin is located in the west of Iran, in Zagros orogeny. The Area of this basin is about 1058 km^2 and the maximum and minimum heights are 3053 and 1755 respectively. This basin is located near UTM 647334 to 682300 north and 3992199 to 3933099 easts. The slope is 16.1 percent and the amount of annual precipitation average is 530 mm. Figure 1 shows the location of this basin in the country, province and also 3'd view of this basin.

The data adopted in this paper are gathered from organizations and companies that are related to natural resources, also satellite images, visiting the field and topographic maps were useful tools for our purpose.

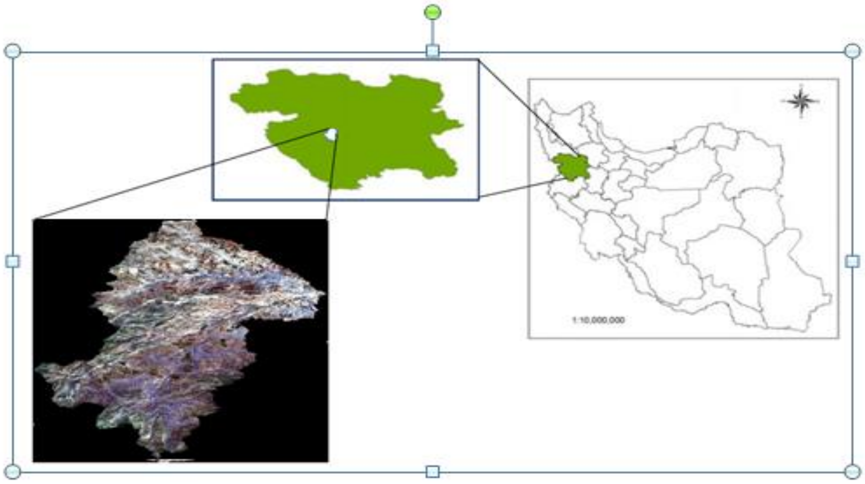

Fig 1. The studied area

Investigation Methods

DSS method, which is used in this study, like AHP, has six steps as:

1- Creating map for each one of the sub-criteria and the existing criteria
2- Determining impact factor for each sub criteria
3- Creating effective criteria map in site selection
4- Determining impact factor of each criterion
5- Creating classification map and locating streams on map
6- Evaluating streams in relation to each other and their classification to construct check dams

Total flowchart of the project is shown in figure 2. According to the main purpose of the project which is considered the spatial classification of check dams, tree model as the analyzing method and compounding of natural spatial factors maps including sedimentation (erosion), runoff, properties related to the basin, facilities and economical-social problems of basin (quality) while each of these factors include several sub-criteria were investigated. Factors and limitations were shown in raster maps with the same Geo-reference and also pixel size (analogous pixels were put on each other).

Zoning map of sedimentation using MPSIAC was created. Slope map was made from DEM, and at last closeness to the roads and villages with determining buffers and margins around them in ARC was identified. Fuzzy standardization of factors was done for values between 0 and 1. This work on maps is intended to create new ones with values between 0 and 1. This is one of the important factors which must be taken into account for comparing several parameters truly. Maximization and purposed methods were applied. Also, linear and nonlinear functions were suggested for analyzing. For example, closeness to the roads means significant cost or reversed relation in standardization of values. In other words, if the site which is considered suitable for constructing dams becomes closer to the road it gets more value. The limitations is standard using Boolean method and there is not any need to weight.

Direct and wise pair methods from AHP were used for weighting the factors. In AHP the factors are compared pairwise and relative importance of factors in determination of a suitability of a pixel for an special purpose for decision maker are evaluated. At the same time, just two factors are compared with each other in which relative values in continuous scales are from 1 to 9. In a squared matrix all the values for classifications are put in a way that the matrix presents two kinds of data. The second is reciprocal with the first one. Analyzes and investigations are done in a software and weights are extracted from a matrix with the highest compatibility and finally, grouping is done. It must be mentioned that the variance of incompatibility in weighting must have a value between 0 and 0.1 (Satty, 1994). Weights of factors, using questionnaires that were filled by relevant experts, were determined in expert choice environment (Fig. 3).

The contribution of each parameter in decision making depends on employer and project purpose and also the condition of the site. So there is not any exact amount for it. For example, slopes less than 20 percent and more than 75 percent according to Cuskelly in 1969 have less usage in preservation programs. In this paper it was decided to give less value to the parameter which has less effect in decision making to eliminate it indirectly (in the classification map).

According to the former projects and the condition of the site, where there are stone resources, a short road and second order stream (based on Stroller method) for ordering streams, that site would be suitable for constructing gabion check dams. Conceptual model of factors and limitations are created in this way.

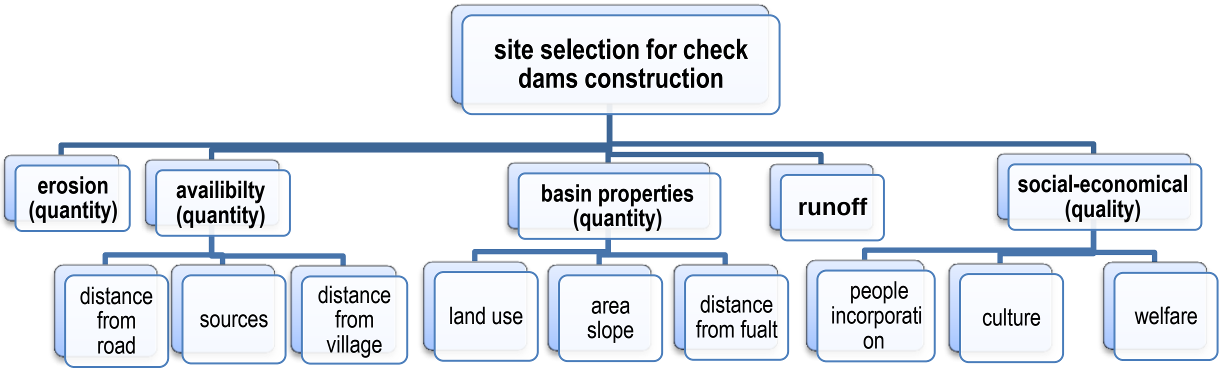

Fig 2. Total flowchart of Siazakh basin research

Results

Creating a map for sub-criteria

In the first step for each one of the sub-criterion (sub-factors) a map is created. Then, in the second step weight of inner layer of each one of the sub-criterion is determined and at last according to outer weight that was made in Expert choice environment, maps were compound and considered criteria maps for the basin would be obtained.

Erosion factor

Erosion and sedimentation intensity map for the study area using MPSIAC model was created. Then, sites with the most erosion intensity got the most inner layer weight. This weight is about 0.402. Figure 3 shows all of the relative weights of the parameters and figure 7 illustrates erosion map of the basin.

Fig. 3. Relative weights of criteria in site selection

Availability factor

This criterion includes three sub-criteria; distance from road, from village and soil resources. The relative weights are shown in (Fig. 4). Distance from soil source with weight of 0.528 has the most one. The same amounts for distance from road and village are 0.333 and 0.140 respectively. These factors have the most impact (Fig. 4). Figure 8 shows basin availability factor map.

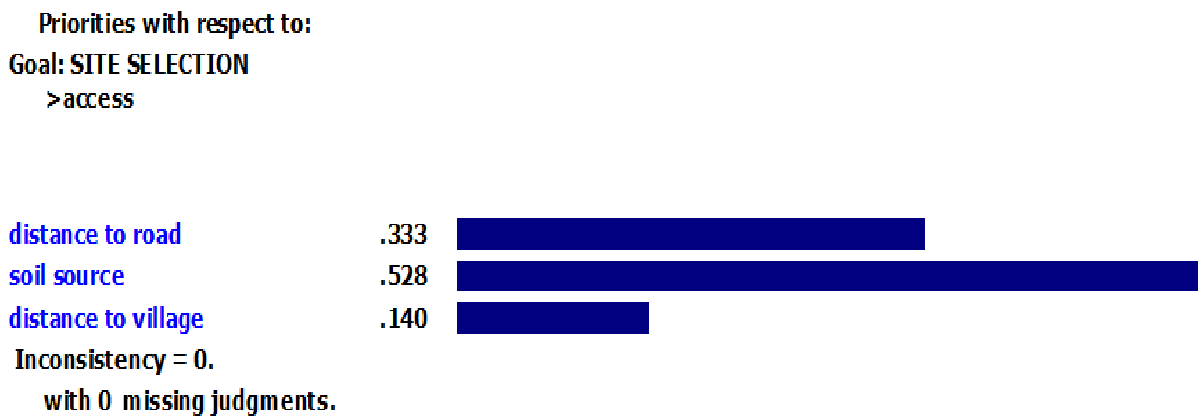

Fig. 4.Relative weights of availability

Distance from village

Closeness to village can be an index for availability to experts, facilities and servicing for constructing correction dams. In this way by increasing the distance from village the cost would be increased too (Forziri et al, 2008).

Distance from communicative roads

For selecting the best site, paying attention to distance from communicative roads is very important. The constructing site, which is too far from these sorts of roads, needs extra roads. This increases the costs (Forziri et al, 2008). The threshold that is considered for this purpose is about six kilometers. This leads to the analysis of all part of the basin which are important to be considered.

Distance from stone sources

Existence of stone sources in constructing site of stony dams (Gabion, dry rock dump & Masonry check dams) is one of the important factors. Actually distance of about three kilometers from stone sources is considered suitable for constructing dams. But if there were not any source near the construction site, the stones would be transported from further distances. Suitable sites for extracting include; Gabbro, Granodiorite and Mallon stones which are spotted with geological maps and satellite image descriptions.

Basin properties factor

This criterion includes three sub-criteria; fault, area slope and land use. Slope with the highest weigh of about 0.655 is the most important sub-criteria. Figures 5 and 9, show table and relative weight of these sub-criteria.

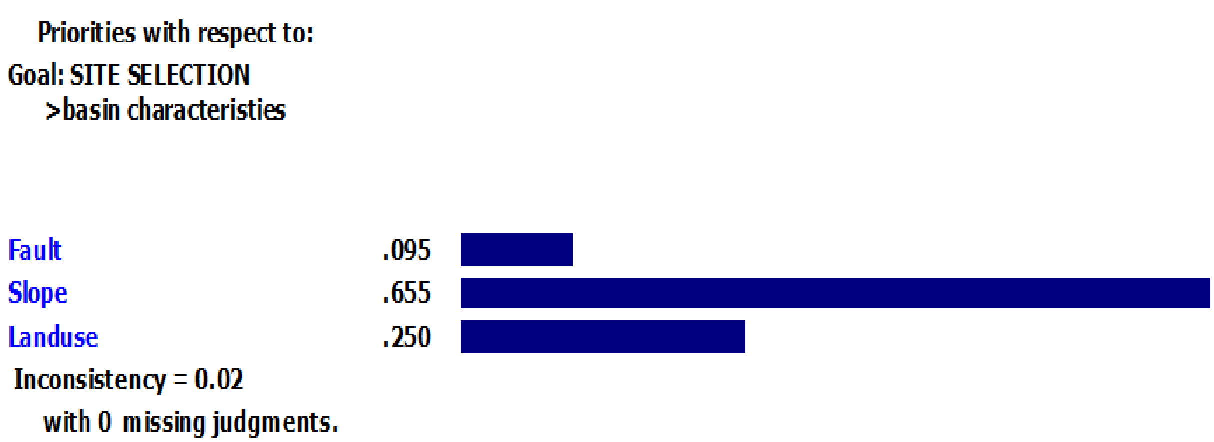

Fig. 5. Relative weight of properties related to the basin sub-criteria

Area slope

One of the important and pivotal factors in constructing check dams is the slope of riverbed. Slope factor and its variance are considered in evaluating storage and sediment volume which exist in the riverbed (??). The more slope in the construction site the less potential for storing water and sediment. Slope has a reverse relation with storage volume. It means that the less slope the more storage volume.

Basin land use

Conservation of the agricultural lands and also high quality rangelands of Siazakh basin from erosion that livelihood and occupation of the inhabitants are based on it has pivotal importance. For determination of basin usages, in this paper started to do administered classification in ENVI 4.2 environment. In this term several usages were determined. Among the entire usages garden, dry land farms, rangeland had the most weights.

Distance from fault

There were special structures of basin geology in most parts of the basin. Also, fault and slide were along each other. Slide in this basin was more important than any other parameter because it treats the structures more than other factors. Thus, areas near fault would have lower inner layer weight in comparison with the areas that are located in further distances. At last a map which shows the location of faults in the basin was created.

Runoff factor

For computing the amount of surface runoff, at first based on soil kind, hydrological group of each soil was identified. Then, using kind and cover percent of vegetation diagram and soil hydrological group, the amount of CN for each part of the basin was calculated. The surface rain flow was calculated by measuring the amount of infiltration of the basin using SCS method.

Economical-social factors of the basin

This criterion includes three sub-criteria; welfare, culture and participation of the inhabitants in practical works and preservation of structures after construction. For each one of the sub-criteria based on filled questionnaires and visiting the field, a map was created.

Figure four and six illustrate relative weights of the criteria and pairwise comparisons. In these figures, welfare had the most weight about 0.540 and also the weights for cultural and participation were 0.297 and 0.163, respectively. Figure eleven shows the map for this criterion.

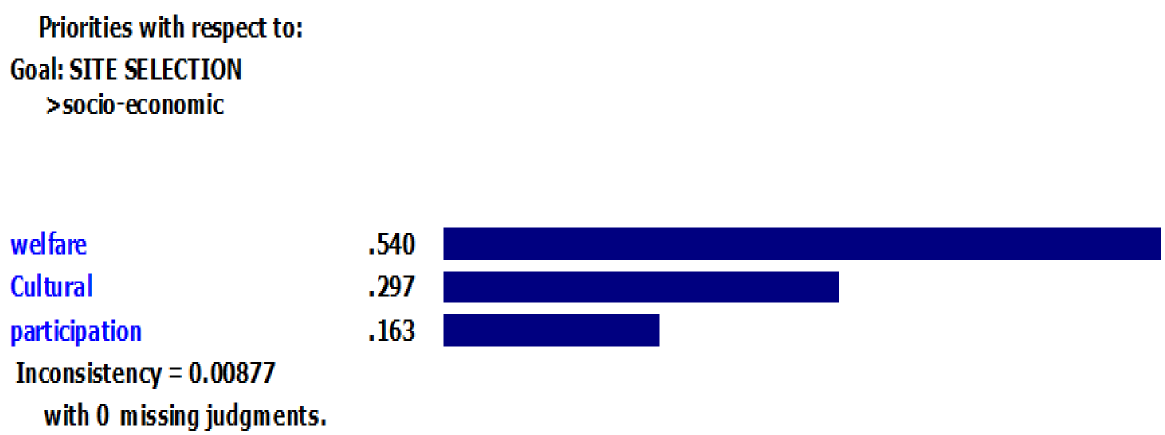

Fig. 6. Relative weight of sub-criteria (economical-social)

Compounding criteria (factors) map and creating prioritization map of the basin

Step 1) with mixing the created layers, compounding index map (CIM) was made. In this map the legend indicates that CIM values are ranged from 1 to 10. One is the least value according to the purpose. While ten shows the most importance toward the purpose. In this way fitness map would be made. Step 2) the divisions of this map were made based on pixel values of compounding index map. The result of this step is the prioritization map of the basin (Fig.12). Step 3) by allocating second and third graded streams on the prioritization map, the streams which are considered for construction of dams were determined (Fig. 13). From 984 streams in the basin about 36 ones were introduced as proper ones for dam construction and their relative weights were determined (Table1).

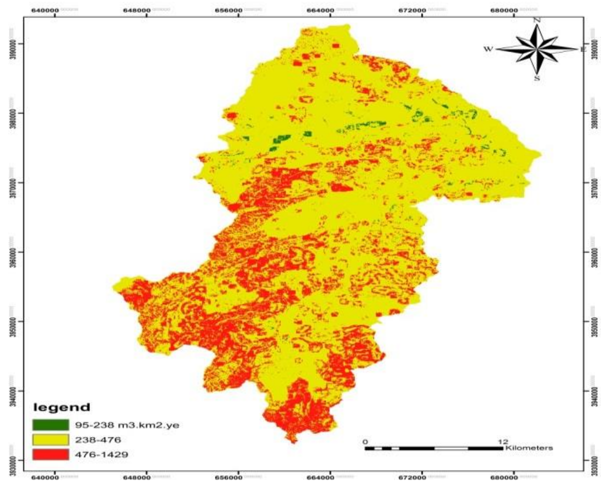

Fig. 7. Erosion criteria map

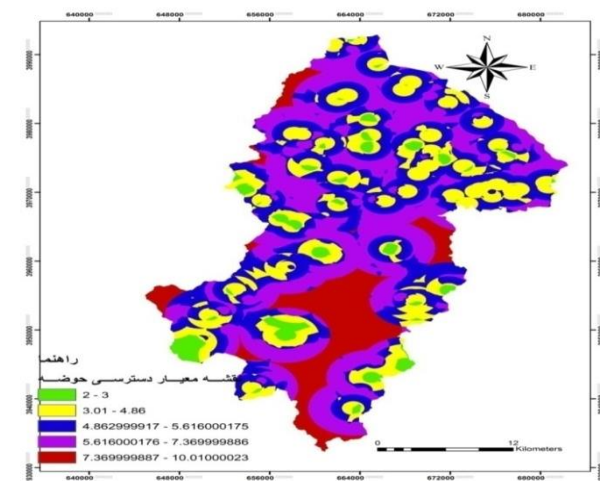

Fig. 8. Availibility criteria map

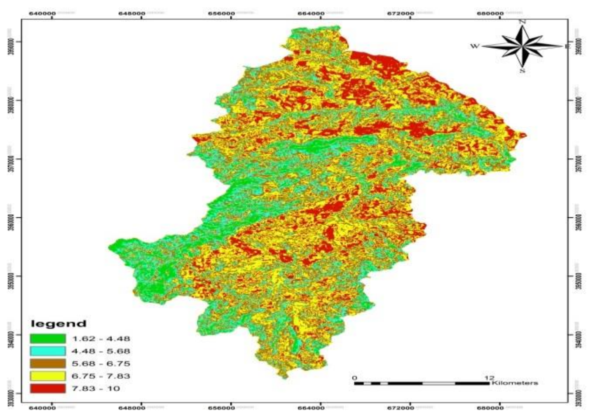

Fig. 9. Basin properties criteria map

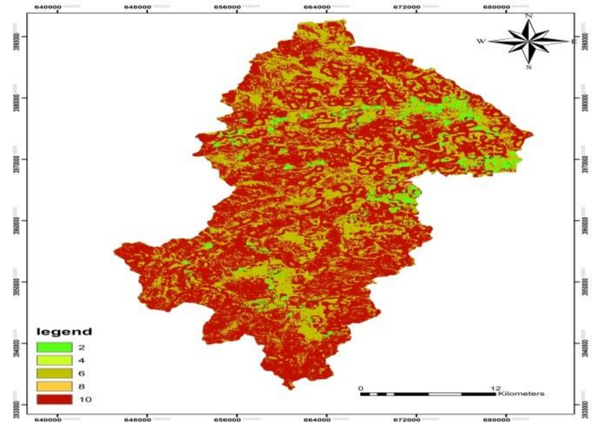

Fig. 10. Runoff criteria map

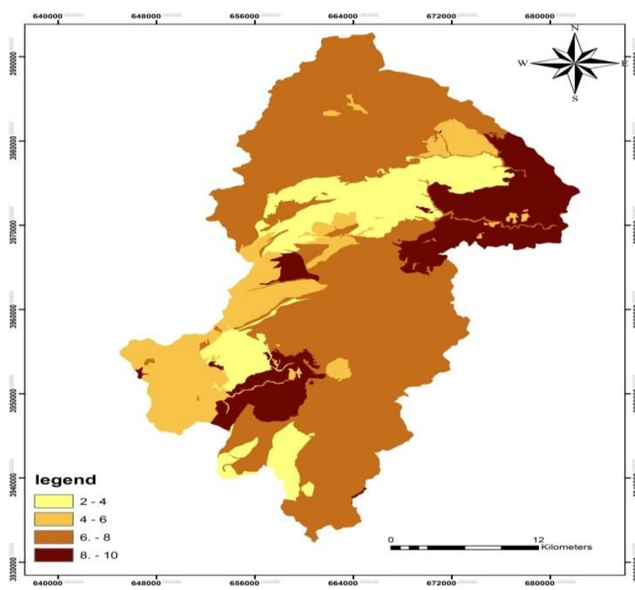

Fig.11. Economical-social problems criteria compounded map

Table 1. Location and length of prioritized steams of the basin

Stream code	X UTM	Y UTM	Length of stream in meters	Priority degree	Ultimate weight
644	677563.4	3973431	4602.89	1	0.138
572	673996.7	3971206.8	420	2	0.132
596	674052	3972099	864.07	3	0.129
608	673727.4	3971623	752.99	4	0.124
611	673927.2	3971909	537.22	5	0.119
626	673307	3972102	1870.21	6	0.118
433	663553.8	3962990	1107.29	7	0.113
417	656275.8	3963579	2331.14	8	0.112
576	664541.6	3971421	611.66	9	0.108
594	664199.2	3971647	994.04	10	0.107
597	664758.6	3971695	143.74	11	0.106
598	666042.5	3971130	2754.68	12	0.104
599	664826.3	3971886	379.41	13	0.99
278	661817.3	3954545	1639.92	14	0.97
277	661586.2	3954132	1268.94	15	0.96
264	662351.4	3953678	597.26	16	0.94
260	659880.7	3953082	1741.98	17	0.92
279	664300.8	3955295	1870.78	18	0.90
259	659074.4	3953536	395.01	19	0.85
262	659250.4	3953664	167.92	20	0.83
263	659366.2	3953878	368.31	21	0.77
270	659103.4	3954099	762.09	22	0.76
273	6592912.2	3954755.1	263	23	0.72
285	658047	3955007	2307.9	24	0.69
455	671078.3	3961499	2331.64	25	0.67
451	655790.2	3963278	2064.54	26	0.65
448	655304.7	3962999	1522.06	27	0.61
439	655111.2	3962800	1476.07	28	0.57
432	654783	3962346	1365.26	29	0.56
404	655897	3959909	1079.61	30	0.52
394	656371.3	3960344	1642.73	31	0.51
409	654892.8	3960550	2015.09	32	0.48
412	657137.9	3960182	647.19	33	0.45
420	655685.4	3960989	312.23	34	0.44
421	656883.1	3960893	986.52	35	0.42
423	657530.5	3960953	1242.06	36	0.39

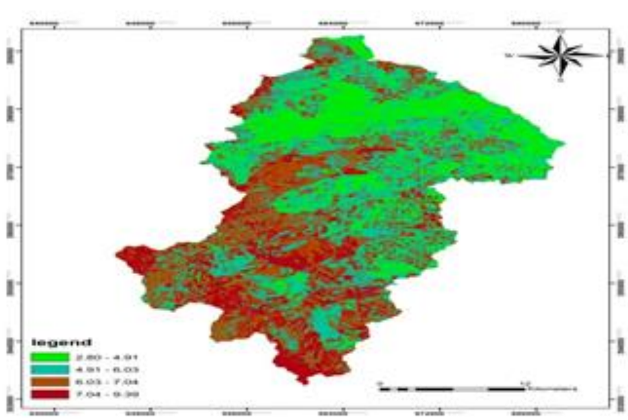

Fig.12. Prioritization map

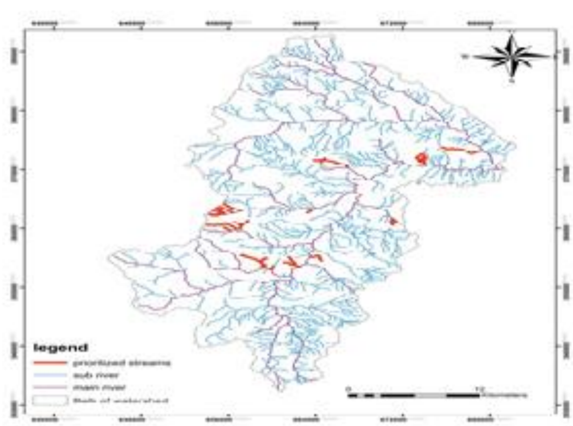

Fig.13. Prioritized streams map

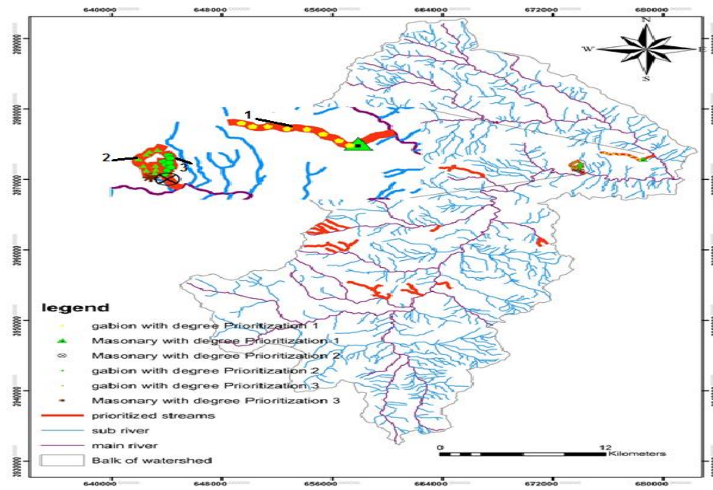

Fig.14. Allocation and priority of correction dams for three prioritized streams

Discussion and conclusion

Compounding index maps for programming were classified. With this investigation and analyzing, site priority to check dam construction in the basin was determined. In this study, prioritization was considered logically. By comparing this study with other cases, one realizes that research has more importance. This study was done in Sakhar plain, which is located in northern part of Italy and west south of Toronto city, which is considered an alpine place. In this research SMCE beside employer opinion was applied for compounding criteria to create land fitness map for burying Garbages (Geneletti, 2009,). In another study in a place located in Menshad in Yazd city, decision making technology with environmental factors and limitations (two linear and polygonal groups) related to determination of lands, which are prone to landslide based on area condition and kind of data, was investigated (Abdolkhani& Jamali، 2009). By paying attention to the aforementioned studies and some others that are the same as these two studies, it can be recognized that there is not any especial frame for selecting proper criteria. In another word it is better to select suitable criteria based on employer opinion, site condition and also purpose of the decision. For the basin, for three prioritized streams the decision was as follows; for the first one eight gabion check dams, for the second one eight and for the third nine were considered. However, for sedimentation of small sized particles in the end of the prioritized streams, it is suggested in the areas that have high temperature difference between the seasons about 70 degrees, in which construction of this kind of dams would be failed, to use gabion check dams with concrete core instead of Gabion check dams without core.

About sensitivity and weight; erosional factors with the relative weight of about 0.402 was the most important criteria and economical-social problems with the least weight of about 0.67 was the least important criteria. A source (soil and stone), which is a sub-criterion of basin availability factor with relative weight of about 0.528, was found to be more important than road availability and closeness to village.

According to the purpose and situation of the project it is possible to decrease or increase factors and limitations. For example it is needed that people in the study area to participate in practices and projects that are near their villages and farms. In these projects with having information layers and also considering several purposes such as reducing erosion, closeness of the preserved areas to roads and villages or other important places in decision making, suitable sites would be selected. With creating this model, problems of complex spatial programming would be solved easily. In this way, evaluation of finished projects would be possible. Also it is possible that with fitness maps and sites for running the former projects in which traditional methods were used, evaluation and site selection become easier. This model with only little calibration according to project purpose is suggested in weightings for the same sites.

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