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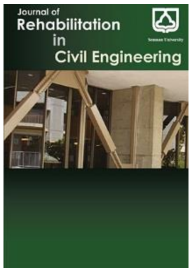

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Forest Road Design Combining Common Design Techniques and GIS (Case Study: 2nd Series of Liresar Forest)

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ABSTRACT

Nowadays, it is necessary to apply modern techniques for the design of road networks, especially roads passing through ecosystems such as forests, in order to reduce operating costs, prevent further degradation of the environment, increase road efficiency and achieve sustainable development goals. In this paper, a new way of designing the road is presented. New design method has the ability to analyze a large amount of information in a variety of digital layers using GIS while being able to store, recover, and analyze information through multi-criteria decision-making process (AHP) and routing algorithms at high speed and precision. The output of the proposed design method (combining information with AHP via Dijkstra algorithm in GIS software) is compared with the existing forest road in the 2nd series of Liresar in Mazandaran province of Iran, designed using common methods. According to experts, hydrological criteria (0.408) and environmental criteria (0.375) have the highest importance and weight in comparison with other criteria in forest road design. The results show the map of area's capability for road construction is prepared for road design with better functionality and less adverse effects on the environment using the divider method compared to conventional topographic maps. Finally, the design of the new road in comparison with the existing reduce the slope (5%), increase access (15%) and reduce the cost of construction (30%).

1. Introduction

Developing forest roads is necessary for various activities including resource management, wood harvesting, wildlife conservation, preservation of plant diversity and endangered species, recreation, pest and disease control, and firefighting. On the other

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hand, road construction in the forest is considered as one of the factors of destruction of natural resources [11,17]. Basic measures to reduce the environmental damages of roads to the forest ecosystem should begin with the design and planning of the forest road network. In the design of the forest road, attention to important issues such as land slope, geographic direction, river and waterway status, forest mass status (in terms of volume, density and type of habitat), geological formation, soil condition, location and potential talent and capacity of the land can reduce the damage caused by the construction of the road and further disturbance of the forest area. Optimal management of forest areas and the practical implementation of forestry plans directly relate to the quality and quantity of design and construction of forest road network in order to access all levels of the forest [4,6,10].

Today, forest road designers, using digital elevation models (DEMs) in the GIS environment for mountainous and sloping areas, are designing the roads with less time and money [15]. If forest roads are well designed and distributed, they would have the least damage to the forest and habitat, and the forest would be in its best situation from the optimal management point of view. Hosseini (2003), using the GIS method, studied and designed the forest road network in the Kheyroud forest near Noshahr, and his findings led to the optimal design of the road network by means of map superposition in the GIS format. He was able to pass the road using various digital maps such as slope, geology, hydrology, etc. so that the maximum length of road coverage would be achieved in the form of optimal design for a given road [7].

In order to design a road with the least cost to determine the final path by integrating the environmental and functional objectives of GIS software in the forests of Turkey, Akay et al, (2004) managed to suggest the roads with the least cost of design, construction and maintenance for transportation [2]. Akay (2003) developed new ways of designing forest roads to explore new design methods using linear programming in the state of Washington, and his findings showed that the design using this method plays an important role in reducing the cost of designing the route and increasing the accuracy [1]. Tan (1992) studied the problem of locating suitable paths in the forest using RS and GIS to complete the forest road network in Austria. He proposed the use of compulsory solutions to implement optimal routes and applied a dynamic programming approach to spatial data and satellite imagery completed on a computer to model the transportation network. [16]

Imani et al, (2012), using GIS software technology and with the help of the shortest path algorithm designed a route with lower length and construction cost. He showed that the length and construction cost of a route designed by the shortest path algorithm is 19 and 21 percent less than the length and construction cost of a route designed by the traditional methods. This paper, in addition to the case study of the 2nd series of forest road network, using the GIS capability of the No. 35 Liresar basin of Mazandaran province of Iran and utilizing the analytic hierarchy process (AHP) is intended to introduce more effective parameters in the design of the forest road while considering the technical and economic criteria, and the environmental criteria (principles of sustainable management) [8].

Peter Hruza (2013) developed new ways of designing forest roads to find out whether an inclusion of the ecological criterion in the forest road design will change the parameter of the longitudinal gradient of forest hauling roads and whether these changes will have an effect on the accessibility of forest stands by timber hauling machinery. The possible changes in the longitudinal gradient can also affect the technology of forest road surfacing and the selection of the appropriate surface type. He could state that an inclusion of the ecological criterion in the forest road network design will bring statistically significant changes in longitudinal gradients of forest hauling roads. The mean longitudinal gradient of the current forest road network is 2.82 % and the mean longitudinal gradient of the forest road network designed with inclusion of the ecological criterion is 4.82 %. The results showed statistically significant changes in the longitudinal parameters of forest hauling roads [12]. Razieh Babapour et al, (2018) focused on solving vertical alignment optimization problem using meta-heuristic algorithms. Two intelligent optimization tools of the genetic algorithm (GA) and Particle Swarm Optimization (PSO) have been used to find a near optimal forest road profile, connecting specified endpoints considering restrictions associated with forest road profile design with cost evaluation. A number of setting parameters such as population size and crossing over and mutation rate in GA and also best group and particle's position in PSO were tested to search the global optimal answer. Results suggested that among the applied optimization methods, the GA was the most suitable one for this feature of the problem since it is able to save optimum position at better solutions with a reduced computed cost. From the cost point of view, it was cleared that optimizing the fixed length of road profile applying GA, with different population size, would be better for big numbers of control points but smoother for low numbers of control points [13].

2. Materials and Methods

2.1. Study Area

The second series of the Larisa forestry plan is located in the watershed basin No. 35 and is one of the four series of the basin. From the administrative and jurisdiction point of view, it is part of the forestry plan of the Department of Natural Resources and Watershed Management in Tonekabon, district of the Department of Natural Resources and Watershed Management of Noshahr, Mazandaran Province of Iran, and is bounded from the north to the series 3 and 4 of Liresar, from the east to the series 1 of the Masgali forestry plan, from the south to the series 1 of Liresar, and from the west to the watershed No. 34 of Sehezar. The location of the forest cover and its area is shown in Figures (1) and (2).

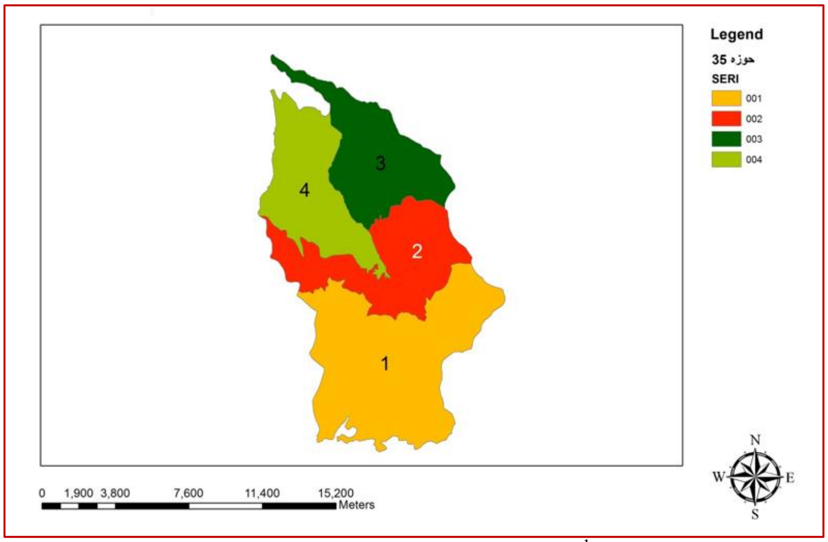

Fig. 1. Forest cover map of the study area – 2nd series of Liresar.

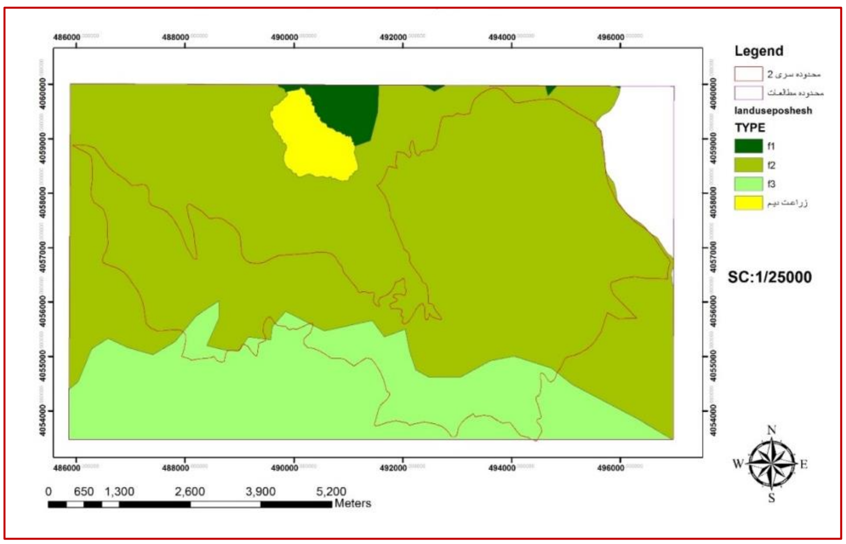

Fig. 2. Location of 2nd series in the drainage basin 35 in Liresar- cover density map.

2.2. Research Methodology

In order to design and construct any new road, the first requirement is to choose the most suitable location that is made following the technical issues at the minimum economic cost. In order to reduce the damage of road construction projects to environmental resources, and in other words, to achieve the sustainable development goals in the national planning, as well as to reduce the repair, maintenance and reconstruction costs, the environmental factors should be inevitably involved in the routing process of various roads. However, involving more than two or three factors influencing the design of the road route with conventional methods is simply not feasible and makes the work process more complex. To solve this problem, new computer technologies such as the GIS can be used today. By combining the studies of the conventional way of forest road design with the capabilities of GIS software, the proposed routes could be designed with the highest adaptation to the environment and the lowest possible cost for construction and maintenance compared to the past.

In this research, by studying the available resources in the national forest, rangeland and watershed management organization, reviewing the documents related to the topic and discussing with the experts, the required data were collected and then, by reviewing the topographic maps and the forest plan consultant studies with the scale of 1: 25,000 and the Spot 2012 satellite images in the Google Earth and field surveys, the desired database is compiled. Then, the effective factors on routing in the area were identified and using the data of the digital base maps available in the booklet of the Liresar forest plan consultant studies, the information layer and the map of each of these factors were prepared in GIS software. These factors include slope, slope direction, soil, geology, erosion, land use, crown cover, surface water flow, fault, river, bedrock, instability, penetration, landslide, flood intensity, and deposit. Then, these factors were classified into four groups (main criteria) of geology, environment, hydrology, and tectonics, and since these factors do not have the same weight or external value in terms of the importance of influencing the route design, they need to be prioritized and weighed against each other.

In order to weigh and determine the external value of the prepared layers, by setting up a questionnaire, the views of experts on the relative importance of the above factors in determining the route are collected and summarized. Then, these factors were weighted by the hierarchical analysis process using the pairwise comparison method and the weight coefficient of each layer was calculated by EC software. In order to prioritize the internal classes of layers, the tables for the assessment of the internal classes of information layers were prepared using the experiences of experts in the field of forest road construction. By multiplying the coefficient of significance calculated for each layer (using the pairwise comparison-AHP) in the table of values of the internal classes of the layer and assigning the resulting multiplication to the individual pixel of the information layer and summing them using the Arc GIS software, the layers are integrated, and finally, the capability map for the road construction was far superior to the common road map in the study area.

Next, in order to design the route, the shortest route based on the Dijkstra algorithm (one of the algorithms used to calculate the shortest route from the fixed destination) was used. Then, the cost surface map was prepared for the study area. This was done by reversing the values of the internal values of the layers in the area's capability map, and by designating the required and recommended points for start, a route was designed with the least length and cost based on the shortest route method using the distance function in the GIS software. Ultimately, the designed route and the existing route were located and compared on the map of area's capability.

According to the expert review and collected expert opinions, slope and slope direction factors and the pedologic, geologic, river, surface flow, fault, erosion, landslide, bedrock, penetration, deposit, flood, flood intensity, instability, land use, and crown cover studies as information layers, the influential factors in designing the road were identified. The slope and slope direction layers were produced using a DEM map (with the topographic line spacing of 20 m).

2.3. Database Generate

The collected data was transferred to ArcGIS as the basic information, and then, with the data leveling and conversion of the coordinate system in the GIS environment, database was produced with different layer titles:

The 3D Tin map used to prepare the 3D, 1: 25000 digital topographic maps provided by the survey organization and the Hillshaid command in the GIS software; the hydrologic status map of this factor indicating the runoff production potential in an area; the existing road map that the length of the existing roads in series 2 is totally 86 kilometers, shared with the series 1 of 9.7 km, with series 3 of 4.5 km and with series 4 of 14.3 km. The existing road is a two-lane earthy one. The study area map and the DEM layer map are shown in Figures (3) and (4).

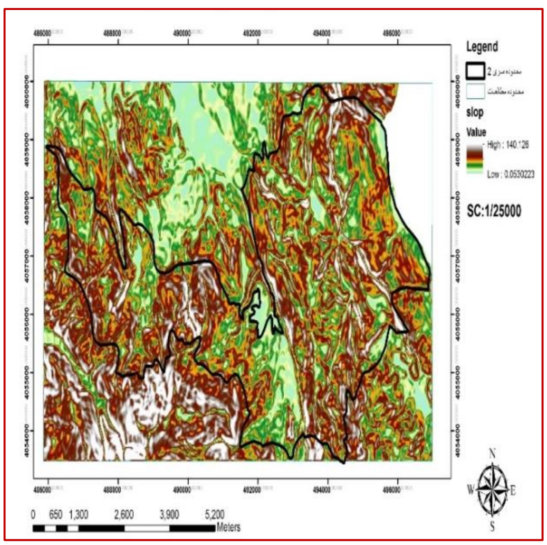

Fig. 3. Preparing slope map of the study area using digital elevation model (DEM).

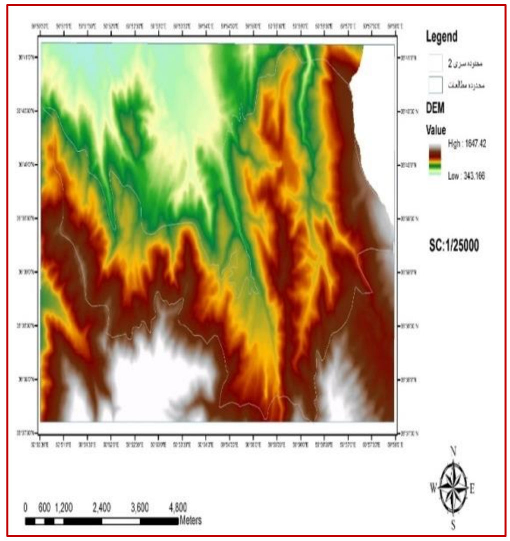

Fig. 4. Preparing slope map of the study area using digital elevation model (DEM).

After generating the database in the GIS software environment to design the road route like the divider method, in which overlapping of two or three maps, including topographic map of the area and surface flows, a single map for road routing is prepared, it is also possible in GIS that the maps prepared in the software database are combined and a single map is created for road routing. This single map is actually the capability map of the study area for road construction.

Since each of the information layers created as influential factors in the database has different levels of effectiveness in generating the capability map of the area for road construction, they should be weighed against each other so that layers of greater importance are rated as more important in terms of decision making. This is done using the pairwise comparison method in the analytic hierarchy process (AHP) and by consulting the experts in the relevant questionnaires.

2.4. Formation of Hierarchical Structure (AHP)

The analytic hierarchy process is a flexible, robust, and simple method used to make decisions in situations where conflicting decision-making criteria make choosing between options difficult. This multi-criteria evaluation method is the most effective method for determining the importance of criteria used to determine the relative relationship between the criteria.

In order to reduce the damage of road construction projects to environmental resources, and in other words, to achieve the sustainable development goals in the national planning, as well as to reduce costs of repair, maintenance and reconstruction, the environmental factors such as slope, slope direction, soil texture, distance from the flow network, slip sensitivity, erosion sensitivity, distance from the fault, etc., in the routing process of different types of roads should be inevitably involved. These factors are classified into four groups (main criteria) of geology, environment, hydrology, and since these factors do not have the same weight or external value in terms of the importance of influencing the route design, they need to be prioritized and weighed against each other.

In forming a hierarchical structure, the capability map of the area for road construction was determined as the goal. To achieve this goal, it was necessary to examine all four factors of the geology of the area, tectonic status of the area, hydrological cycle of the area and environmental conditions. Therefore, the collected data including the slope, slope direction, landslide, land use, river, crown cover, pedology, fault, erosion, bedrock, soil, hillside instability, penetration, floodiness, flood intensity, deposit and surface flow were classified as factors influencing the route design in the form of sub-criteria or options of these four factors.

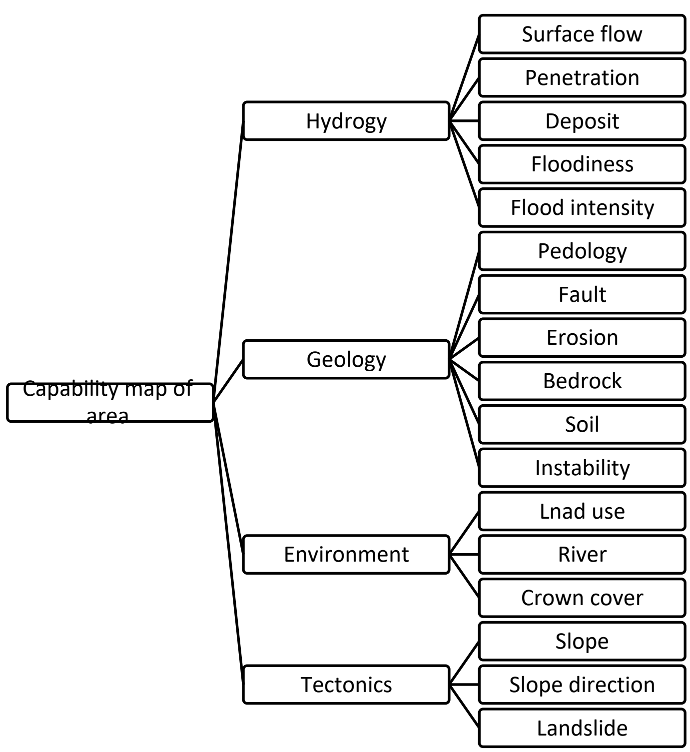

Fig. 5. Classification of criteria and sub-criteria for target function in AHP.

45 questionnaires were prepared and distributed among the target groups among which 43 questionnaires were collected. From the content of the responses, 32 responses had favorable and reasonable conditions and therefore, for the pairwise comparison, their mean value was calculated. The AHP was performed in two steps; first, a pairwise comparison between the options or sub-criteria with the main criterion and then, the pairwise comparison between the main criteria using the EC software, the results of both steps are shown in Tables (1) to (5).

Table 1. Average of pairwise comparison of geological sub-criteria from 32 questionnaires.

	Pedology	Fault	Erosion	Bedrock	Soil	unsustainability
Pedology	1	3.0	1.0	3.0	1.0	1.0
Fault	0.33	1	3.0	2.0	1.0	5.0
Erosion	1.0	0.33	1	3.0	1.0	1.0
Bedrock	0.33	0.5	0.33	1	5.0	3.0
Soil	1.0	1.0	1.0	0.2	1	1.0
unsustainability	1.0	0.2	1.0	0.33	1.0	1

Table 2. Average of pairwise comparison of Hydrological sub-criteria from 32 questionnaires.

	Runoff	Floodiness	Deposit	Infiltration	Flood severity
Runoff	1	5.0	5.0	1.0	5.0
Floodiness	0.2	1	5.0	3.0	1.0
Deposit	0.2	0.2	1	3.0	7.0
Infiltration	1.0	0.33	0.33	1	3.0
Flood severity	0.2	1.0	0.143	0.33	1

Table 3. Average of pairwise comparison of tectonic sub-criteria from 32 questionnaires.

	Slope	Slope direction	Landslide
Slope	1	3.0	3.0
Slope direction	0.33	1	3.0
Landslide	0.33	0.33	1

Table 4. Average of pairwise comparison of environmental sub-criteria from 32 questionnaires.

	Land use	River	Crown cover
Land use	1	9.0	5.0
River	0.11	1	3.0
Crown cover	0.2	0.33	1

Table 5. Average of pairwise comparison of main criteria from 32 questionnaires.

		Main criteria			
		Geological	Environmental	Hydrological	**tectonic**
Main criteria	Geological	1	4.0	4.0	**2.0**
	Environmental	0.25	1	1.0	**3.0**
	Hydrological	0.25	0.1	1	**4.0**
	tectonic	0.5	0.33	0.25	**1**

Valuation of internal classes of information layers (Vi)

Due to the fact that in each of the prepared information layers, some parts are suitable for road construction and some other parts are not suitable at all, and there may also be parts that are of intermediate value for road construction, therefore, it is necessary that the internal classes of each information layer of the influential factors are individually classified and internally valuated for the suitability of road construction. The classification and valuation of each of the information layers (influential factors) was carried out by assigning numbers from 0 to 10 and asking the expert opinions; 10 has the highest value and 1 has the lowest value, and the zero number means no value for road construction (e.g. Tables 6 and 7).

Table 6. Values for unsustainability layer.

Hillside type	Code	No. of value
unsustainable hillsides	0	**1**
Relatively unsustainable hillsides	1	**5**
Relatively sustainable hillsides	2	**9**
Sustainable hillsides	3	**10**

Table 7. Values for slope layer.

Slope	No. of value
0-10	**10**
11-20	**9**
21-30	**8**
31-40	**7**
41-50	**6**
51-60	**2**
>60	**1**

3. Results

Given the number of questionnaires (32 questionnaires), the weight of sub-criteria and main criteria were calculated using EC software. This software is designed to analyze multi-criteria issues using the AHP technique and is a suitable option for calculating the weights [5]. The weight coefficients of the main criteria of geology, environment, hydrology, and tectonics and the sub-criteria are calculated and described in the following tables.

The results of the weighing scales of the sub-criteria and main criteria using AHP method by experts, according to Table 8, showed that among the four main criteria, the hydrology criterion weighting 0.408 is of great importance and then, the environment criterion weighting 0.375, tectonics weighting 0.131 and geology weighting 0.086 are in the next priorities.

Table 8. Weighting factors for main criteria.

Criteria	Geological	Environmental	Hydrological	tectonic
Factors	0.086	0.375	0.408	0.131

From the geological criteria options according to Table (9), the experts attributed the highest weight coefficient to the instability option of 0.23 and the lowest value to the bedrock of 0.076.

Table 9. Weighting factors for Geological Sub-criterion.

criterion	Pedology	Fault	Erosion	Bedrock	Soil	unsustainability
Factors	0.205	0.709	0.205	0.706	0.204	0.230

From the environmental criteria options according to Table (10), the experts attributed the highest weight coefficient to the river option of 0.672 and the lowest value to the land use of 0.063.

Table 10. Weighting factors for environmental Sub- criterion.

criterion	Land use	River	Crown Cover
Factors	0.063	0.672	0.265

From the hydrological criteria options according to Table (11), the experts attributed the highest weight coefficient to the flood intensity option of 0.372 and the lowest value to the deposit of 0.044.

Table 11. Weighting factors for Hydrological Sub- criterion.

criterion	Surface flow	Floodiness	Flood severity	Deposit	Infiltration
Factors	0.113	0.355	0.372	0.044	0.115

From the tectonic criteria options according to Table (12), the experts attributed the highest weight coefficient to the slope option of 0.584 and the lowest value to the slope direction of 0.135.

Table 12. Weighting factors for tectonic Sub – criterion.

criterion	Slope	Slope direction	Landslide	precipice
Factors	0.584	0.135	0.281	0

In the next step, by combining maps in the GIS software environment, a capability map of the study area was prepared for the forest road construction. The capability map pixels were obtained from the sum of multiplying the calculated weight coefficient in the multi-criteria evaluation process by AHP method in the corresponding information layers (each cell of the maps of combining the main criteria).

By executing the Raster calculator command from the toolkit, the area's capability map is generated in the GIS software environment. The value of each cell of this map represents its relative capability to cross the road from that cell. Considering that in the intra-layer classes, the low values indicate low suitability, so in the capability map for road construction, the low-value sites also indicate the low suitability of this area for road construction. The suitability or unsuitability in the capability map is divided into five categories and is characterized by the following colors in the GIS software environment:

1. Bad - red

2. Unsuitable - orange

3. Relatively suitable - yellow blue

4. Suitable - bright green

5. Good - dark green

Figure 6 shows the capability map generated from the area.

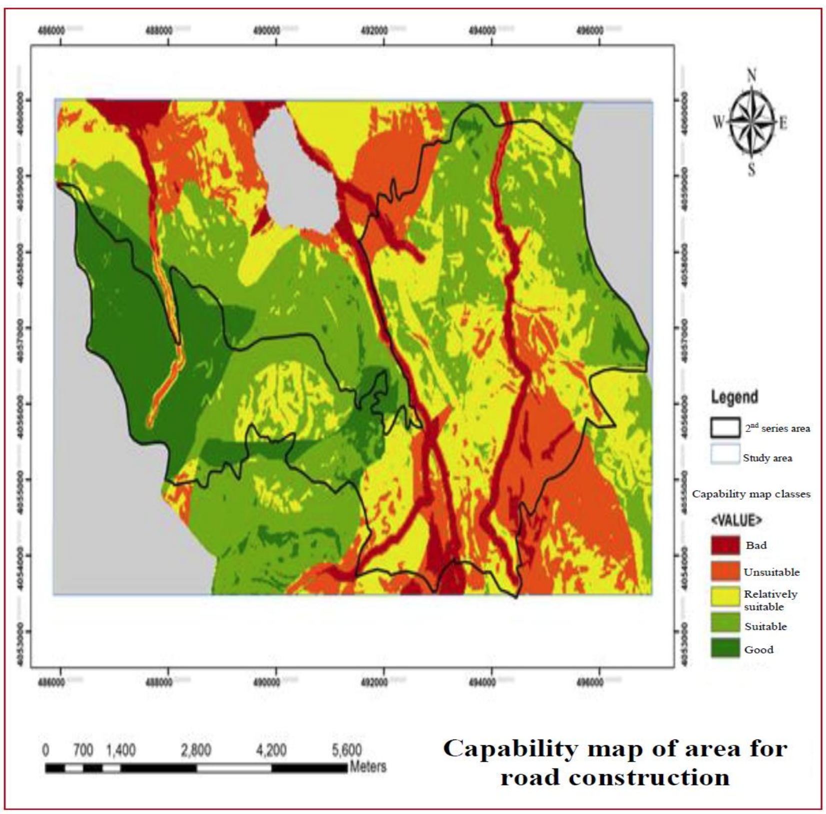

Fig. 6. Map of the area's capability for road construction.

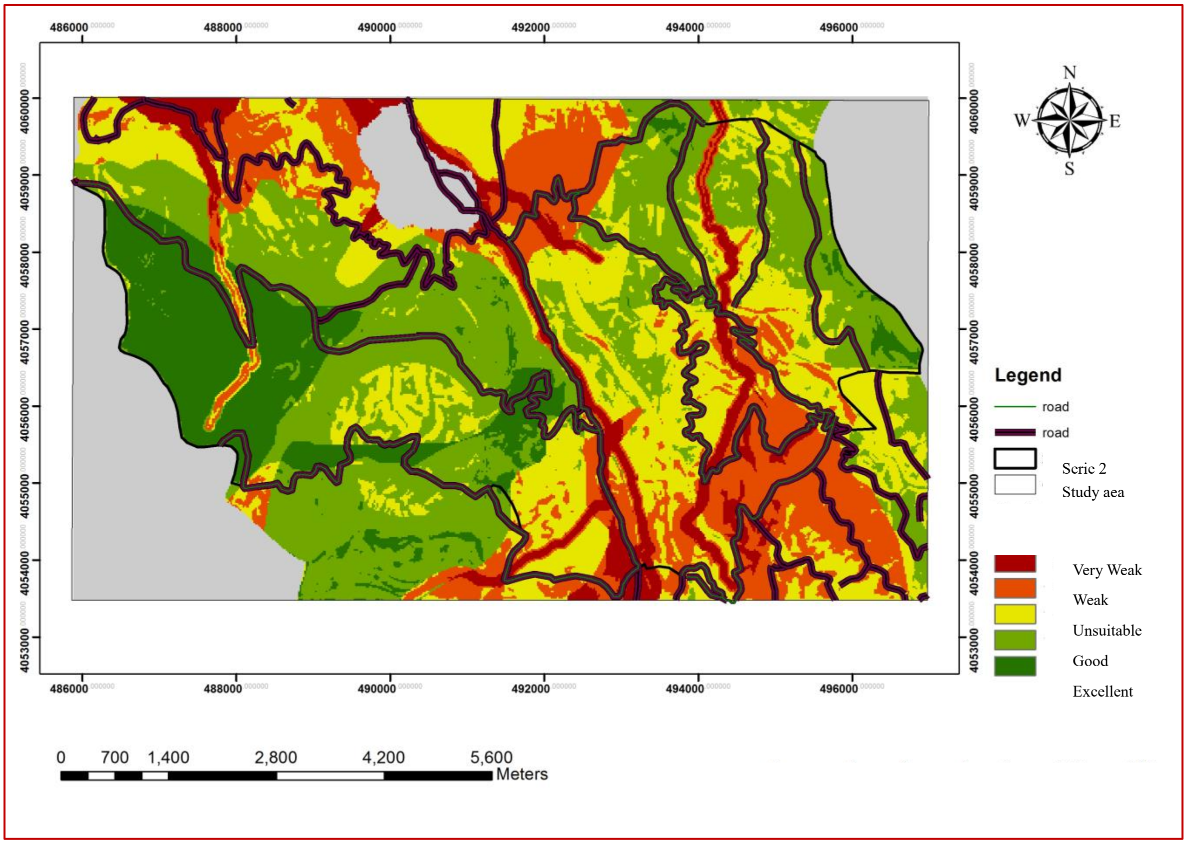

Fig. 7. Map of the area's capability for road construction by locating the existing road.

Finally, in designing the road network for the 2nd series of Liresar (study area), using the Cost Distance function in GIS software and the existing road junctions as selected compulsory points, the forest road network was designed with the aim of the least length and cost. The number of compulsory points was considered to be 18 points, and all of design routes were merged and represented as a single network in Figure 8.

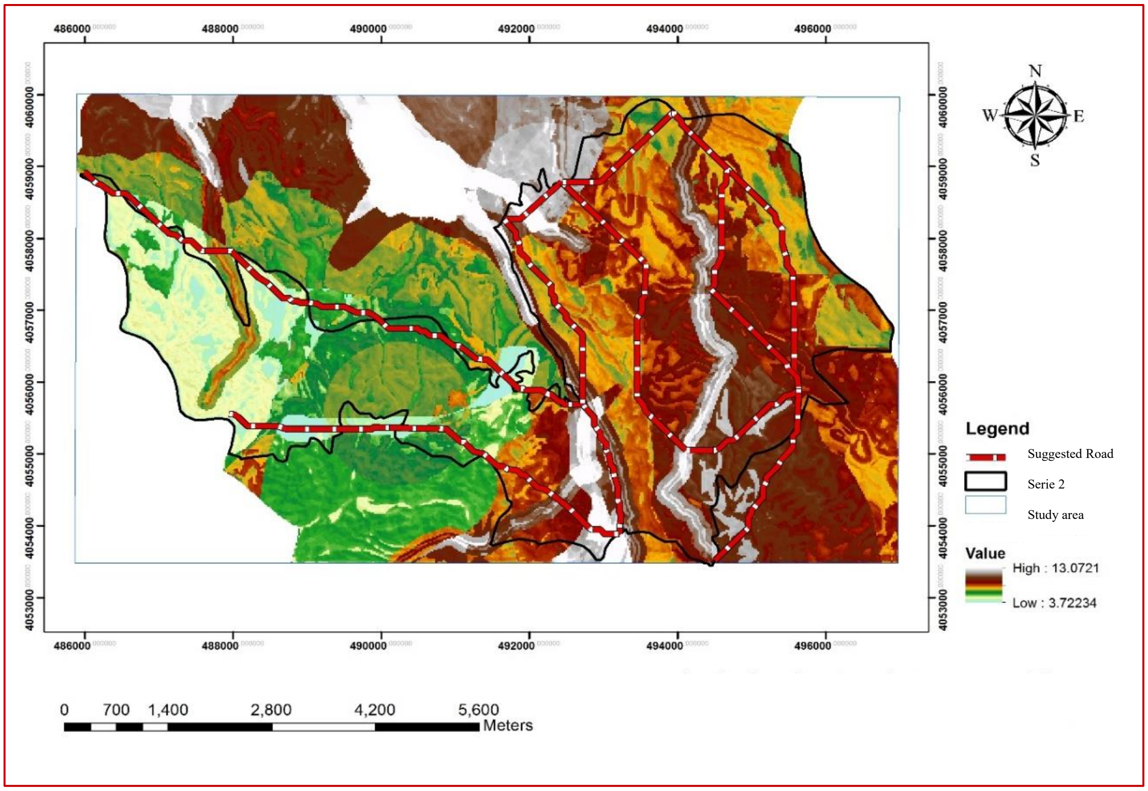

Fig. 8. Cost surface or friction map for road construction in the study area.

4. Discussion

The results of the experts' opinions on weighting the four main criteria of geology, hydrology, environment and tectonics showed that the hydrological criterion with the weight coefficient of (0.408) and environment (0.375) had the highest value, and the tectonic (0.131) and geological criteria (0.086) are in the next rank with the lowest value, respectively.

Assigning the highest weight to the hydrological criterion by experts suggests that, contrary to the premise that treating trees as the main cause of the difference in road construction in the forest with other regions, the main difference between road construction in the forest is the high volume of water and its permanent flow in the forest soil. A general principle in road construction is the fact that the biggest factor in destruction of the roadway and rising the maintenance cost is water. Therefore, in the forest areas, the roadway should be determined first and foremost with regard to the hydrological cycle factor (surface flows) and should not be used as a way to remove water from soil texture. Paying attention to this, while further protecting the roadway and the forest environment, greatly reduces the cost of road construction and maintenance. The forest roads disturb the natural balance of water and should not be neglected in this regard. Forest roads with the removal of vegetation and changes in the natural hydrologic trend of arenas produce sediment and sediment-related consequences. Therefore, hydrologic issues are the first priority in the design of forest roads.

The experts assigned the second largest weight to the environmental criterion with two important river and crown cover options.

Maintaining forest cover and keeping road tracks far from rivers (as one of the most important forest environmental reserves) is essential and inevitable to protect the forest environment and prevent soil erosion and forest morphological changes. On the other hand, in order to reduce the cost of building a forest road, the number of intersection with the rivers should be reduced. Crossing the river, in addition to changing the regime of surface water and affecting the bed and sides of the river, and ultimately changing the ecological conditions of the river, involves high costs for the construction of bridges and structures, while the maintenance costs of this structures will be high during the operation period.

Using the ability of the GIS software and the superposition of the information layers, a map called the capability map was prepared featuring far superior capabilities to the common topographic maps for the design of the route using the divider method. The generated capability map interprets and categorizes the area according to the existing capabilities of the region, which is consistent with the results of previous research. Therefore, it can be stated that using the above method for generating a capability map is a more appropriate, efficient and less costly method than the conventional methods and is necessary for identifying the areas with the proper potential for road construction, taking into account the environmental issues and the objectives of sustainable development in the country. It can also be stated that the use of the shortest path algorithm in the GIS software for the preliminary prediction of forest roads (Phase I) with the least length and cost of construction and operation provides acceptable results.

This proves the research hypothesis. The discrepancy in the research with previous research suggests that in past research, the slope factor has been reported as the most important factor with high relative weights compared to other influential factors. However, the results of the survey of expert opinions in the present study introduce the hydrological cycle of the region (the river in the first place and the flood intensity in the second place) as the most important factor. Considering that the most fundamental difference between the design of roads in forest areas with other areas is the high humidity in the soil and forest environment, therefore, this research seems to be closer to the realities of road design conditions in forest areas, taking into account the environmental issues.

Finally, the design of the new road in comparison with the existing road has the following advantages:

- Slope decrease by about 5%
- Reduced construction costs by about 30%
- Increased access by about 15%

5. Conclusion

This paper has shown that for forest environment considerations, new ways of designing roads can be used. The proposed route can provide the same coverage for crossing while at the same time, taking greater account of the reduction of the road's destructive effects on nature, and overall (in the context of sustainable development) using the capabilities of the GIS software and the AHP method aims at introducing the environmental criteria (sustainability management principles), taking into account more effective parameters in generating a map of the area's capability to construct the forest road network into the final design, while taking into account the technical and economic criteria.

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