Planning of Forest Road Network and Analysis in Mountainous Area

Erhan Çalışkan
Department of Forest Engineering, Faculty of Forestry, Karadeniz Technical University, 61080,Trabzon, Turkey
erhan_caliskan@yahoo.com

Abstract: Forest roads designing and construction in mountainous areas involves various economic and environmental requirements. For this reason, road managers must consider as many alternative alignment alternatives as possible in order to find the solution that minimizes construction, maintenance cost and negative environmental impacts. The purpose of this study was to design the forest road network using Geographical Information Systems (GIS) based on Multi-criteria Decision Analysis (MCDA) and RoadEng in mountainous area of Turkey. These methods were employed using slope, aspect, elevation, growing stock, hydrographic network, soil, bedrock, and landslide susceptibility map of the study area. Morever, road network generated by GIS-MCDA-ROADENG method compared with existing road networks. Firstly, the required data was collected from the study area. The effective factors that impact on road network in study area were identified and the necessary maps were generated and classified. The next step, related the importance and the role of the mentioned elements in the cost of road construction, the maps prepared were rated using MCDA to determine the weight of both effective factors. Secondly, by overlaying the weighted maps of affecting factors, a forest potential map of road construction was prepared. Thirdly, map was categorized into the three following classes: high, moderate and low capability. On the current map planned road network designed using the RoadEng ® Software. Finally, the planned road network was evaluated by merging the planned road network and road planning potential map based on Backmund criteria. The results of this study showed that planned roads were mainly located high and moderate roading capability (93,5%), distributed on sandy loam and andesite-basalt bedrock (45%) and accessible region (slope < 45%) comprise 26 % of study area. The planned road provided an accessibility of 85% for the logging planning area. The planned road network with 44 km length, 8.9 m/ha road density and 1123m road spacing. These results suggest that multi-criteria evaluation method can be more accurately to design forest road planning in mountainous area. The methodology used for this study can also be applied to the other forest area.
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1. Introduction

Forest roads play an important role in forest management, transportation of wood raw material, protection and a forestation activities in mountainous areas. Incorporating the consideration of technical and environmental issues into manual road planning is a difficult job. More lately, concurrent information management according to the important factors in road planning and rapid assessment of the roads has been made possible using GIS capabilities [1,2,43,49]. One of the main factors in forest road network planning was considering the costs of road construction and maintenance during the initial route location in the field. Since there was a close relationship between the costs of road construction, maintenance and stability characteristics (soil and bedrock stability), it was necessary to locate the roads on the more stable grounds to reduce the total cost of road construction and maintenance.

The road design and construction process is the most expensive and also most damaging activities in forestry, for example; slope failures and mass movement [3]. Forest roads are globally recognized as a main source of sediment yield and pollution of off-site water [4,5,6], in addition to direct loss of [7], and indirect loss of habitat (by the fragmentation of an ecosystem into smaller and more isolated patches) [8]. Forest roads, especially inefficient road networks, generate abrupt edges and, finally, cause habitat and biodiversity losses [9]. To reduce these negative impacts, forest road managers need to look for ways of developing road networks and improving the environmental soundness and public acceptance of road construction activities [10,2,53].

An assessment of the impacts of road construction on the environment must be conducted before road construction to minimize the degree of these impacts. In previous decades, most forest road design criteria was based on accessing timber harvesting sites with the lowest cost possible incurred [11,12,13,14,15,16,54].

In a study, Tan [17] used a GIS to design a skid trail network and explained that some primary data includes stand productivity, volume m^3/ha and that cost and other weighty layers can be provided more satisfactorily.

Gerasimove et al. [18] used a GIS program the process of designing and analysing a skid trail network in Russia and concluded that using GIS as a decision making system can be an efficient method for offering appropriate alternatives in forest road locating.

Multi-criteria analysis techniques are well known as decision-support tools for dealing with such complicated decision making processes, where technological, economical and environmental aspects have to be covered in order to obtain an overall assessment of the decision alternatives [19, 20, 21, 22, 23, 53]. For evaluating the numerous criteria, the analytic hierarchy process (AHP) has become one of the most widely used multi-criteria decision support systems to help users by breaking down these complicated decisions into a hierarchy [24, 25, 26, 27, 28, 53]. There have been numerous articles on the Analytic Hierarchy Process in forestry applications [29, 30, 31, 32, 33, 34]. GIS environment, the combination of AHP provides the possibility of combining different types of information in different scales.

Not only was the manual performance of such analysis very difficult but also time consuming. Unlike manual forest road planning, AHP makes it possible to use the ideas of different experts and to calculate an incompatibility coefficient as well as using quantitative and qualitative criteria [43]. AHP method, with the right choice of features and weights attached to them as it is often the most important factor in the accuracy of the results.

Indeed, the AHP method helps a decision maker to prioritize the goal and formulate a set of criteria. The method also systematically and logically assists in the preparation of evidence toward the selection of the best and most suitable road network alternative from the multi-criteria analysis [29]. In spite of this, MCDA has not been widely used for forest road planning in Turkey. Therefore, the aim of this study was to design the forest road network using Geographical Information Systems (GIS) based on Multicriteria Decision Analysis (MCDA) and RoadEng in mountainous area of Turkey. These methods were employed using slope, aspect, elevation, growing stock, hydrographic network, soil, bedrock, and landslide susceptibility map of the study area. Morever, road network generated by GIS-MCDA-ROADENG method compared with existing road networks.

2. Materials and Methods

2.1. Study area

This study was carried out in Artvin, a forest district covering approximately 4167 ha of the Forest Planning Unit in the Artvin province- northeastern Black Sea region of Turkey. The area was located between 41°32'00"- 41°07'30" of longitude, and 41°32'00" - 41°53 '00" of latitude. The study area is situated in a mountainous area which covers 5175 ha, and has a slope which varies between 0 to 105%. The relief has a very irregular topography, and the elevation ranges from 900 to 2200 m. The mean annual precipitation is 1150mm, with the lowest values being recorded in July and August.

2.2. Methods

In this study, 8 thematic layers associated with layers including slope, soil type, bedrock, hydrographic networks, aspects, growing stock (m^3/ha), landslide susceptibility and elevation, which can influence forest roads and should be considered in the forest road network planning. Forest potential map of road construction was prepared by using these layers and overlaying them. The AHP method has been used to weight the layers and the initial data have been analyzed using IDRISI software [35-49]. The analyzed data were then prepared using ArcGIS 9.3 software. On the current map planned road network designed using the RoadEng® Software. The effective factors were specified by field trips and the study of existing maps. Then using the Digital Elevation Model (DEM), a map corresponding to each of desired factors was produced. In fact, by using the DEM, the slope, aspect, and elevation maps were produced.

2.2.1. Input Parameter

2.2.1.1. Slope:

Slope is one of the main factors that should be noticed at planning forest road network. Slope both directly and indirectly affects many factors such as the volume of excavation and constructability. To provide a slope map, the DEM of the study area was used. The slope map was prepared in percent using the DEM of the study area. The slope map of the study area were classified into three classes (0-45%, 46-70% and >71%).(Figure 1a).

2.2.1.2. Aspect:

Aspect associated parameters such as exposure to sunlight, drying winds and rainfall are important factors in forest road. Aspect was the orientation or direction of slope that is measured clockwise in degrees from 0° to 360°, where 0° is north, 90° is east, 180° is south, and 270° is west. The study area were characterized as north, east, south and west in this study. (Figure 1b).

2.2.1.3. Elavation:

Elevation (height above the sea level) is known by its effects on biological and natural factors. The elevation map of the study area were divided into three classes (250-750, 750-1250 and >1250m). (Figure 1c)

2.2.1.4. Growing stock:

The maps of forest type and volume of stand per hectare were prepared based on the inventory data. One of the other aims in planning forest road network is wood extraction from forest. Road density value is directly related to stock growth of the forest area. The stock growth map of the study area were classified into three classes (0–100, 100–250 and > 250 m^3 ha^{-1}). (Figure 1d)

2.2.1.5. Hydrographic networks:

Streams may adversely affect by forest road. Three different buffer zones were created within the study area to determine to meter the streams affected the stream.(0-20, 20-40 and 40-60). (Figure 2a)

2.2.1.6. Soil:

In each landform unit, the soil was studied by the digging of the soil profile. Accordingly, the item of soil texture is judged to be a factor influencing the forest roads. Soil texture was determined by the Bouyoucos hydrometer method [36]. Soil was classified into different classes (1-The depth of soil is 55-65cm. 2- The depth of soil is about 70cm. 3. The depth of soil is 45cm). (Figure 2b).

2.2.1.7. Bedrock:

Forest road pass through the structure of the bedrock of the land, and affecting construction costs, as well as a very important criterion affecting the performance of the road during the period of use. Bedrock, plays an important role in the planning of forest road route. Bedrock was divided into three classes (Rhyodacite, Granite and Andesite -Basalt). (Figure2c).

2.2.1.8. Landslides susceptibility:

In natural disasters, the most common and the one who suffers most as shown. Vegetation, natural resources such as land and soil, as well as road and bridge projects, as well as harm. This type of landslide areas to be identified in order to prevent damage and route of these areas must not be passed. Landslide susceptibility was divided into three classes (0-33%, 34-65%, >66%).(Figure 2d).

2.2.2. Ground Stability Map

In this study, the Nilsen method [37] was used for producing the ground stability map of study area. This method was based on slope and bedrock maps. By overlaying the soil texture and bedrock maps, the map was prepared ground stability.

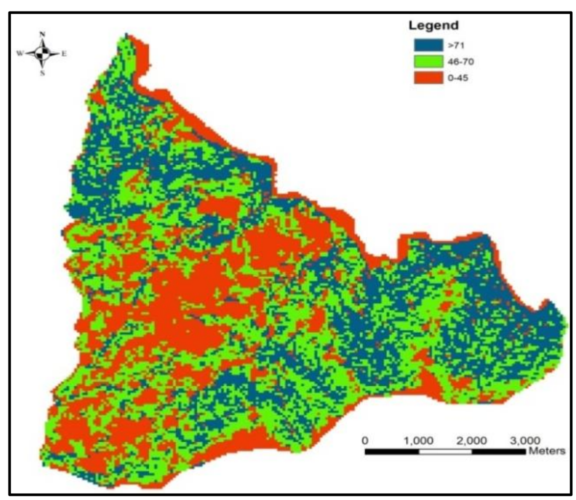
2.2.3. GIS-based multi-criteria decision analysis (MCDA)

GIS-based MCDA is a process that transforms and combines geographical data and value judgments to obtain information for decision making [29-50]. Although several methods exist for estimation of decision criteria in the MCDA, the analytical hierarchy process (AHP) developed by Saaty [38] is the most popular one. AHP is a flexible, yet structured methodology for analyzing and solving complex decision problems by structuring them into a hierarchical framework. It is employed for rating/ranking a set of alternatives or for the selection of the best in a set of alternatives. The ranking is carried out with respect to an overall goal, which is broken down into a set of criteria (objectives or attributes) [29]. In other words, AHP is used to determine the weights of each criterion and analyze the relative importance of these criteria. In this step, prepared in accordance with the importance of their categories on the map using GIS-based MCDA, the factors affecting the maps were rating to determine their weight. In order to apply the AHP method, a questionnaire was used to ask the forest engineering road experts to obtain the relative weight for each criterion. Each questionnaire contained the questions related to the importance and preference of each factor influencing road planning under the stable conditions of the ground. View point of experts record in 8 criteria as compare paired (score of different parameters was among 1 and 9).Then the factors were combined in the form of a weighted linear combination by Eastman [39]:

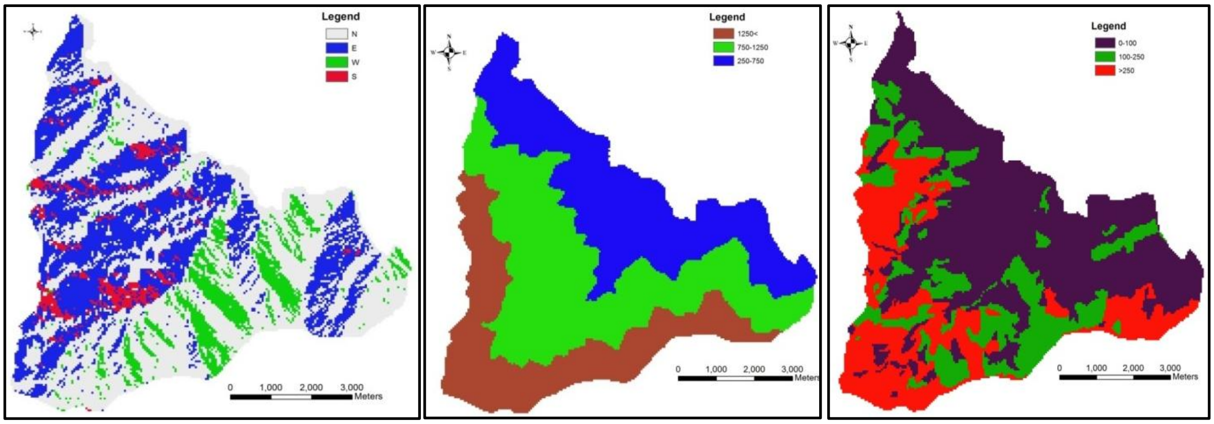
$$S=\sum Wi * Xi \quad (1)$$

Here S is suitability, Wi is layer weight, Xi is the GIS layer value of criterion i.

The IDRISI-GIS and its built-in decision support system module for performing multicriteria decision analysis have been used. This case illustrates the use of the MCDA module using AHP's Pairwise Comparison Method. By overlaying the weighted maps of affecting factors of the initial path location within a GIS, the final map of Forest potential to road construction (FPRC) was prepared. The different information layers are presented in figure 3.

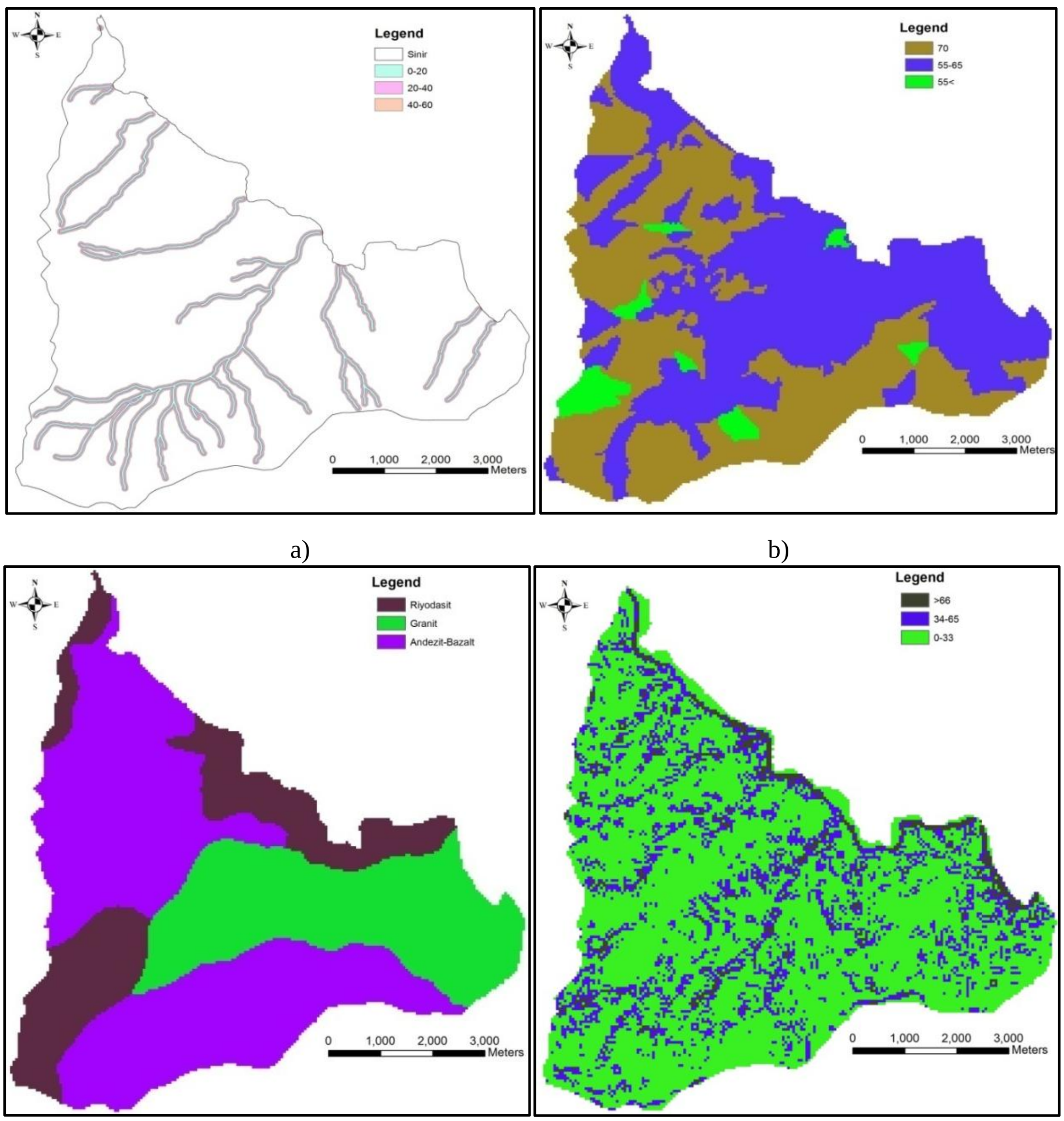


a)



b) c) d)

Figure 1. Slope map (a), Aspect map (b), Elevation map (c), Growing stock map (d)



c) d)

Figure 2. Hydrographic map (a), Soil map (b), Bedrock map (c), Landslides susceptibility map (d)

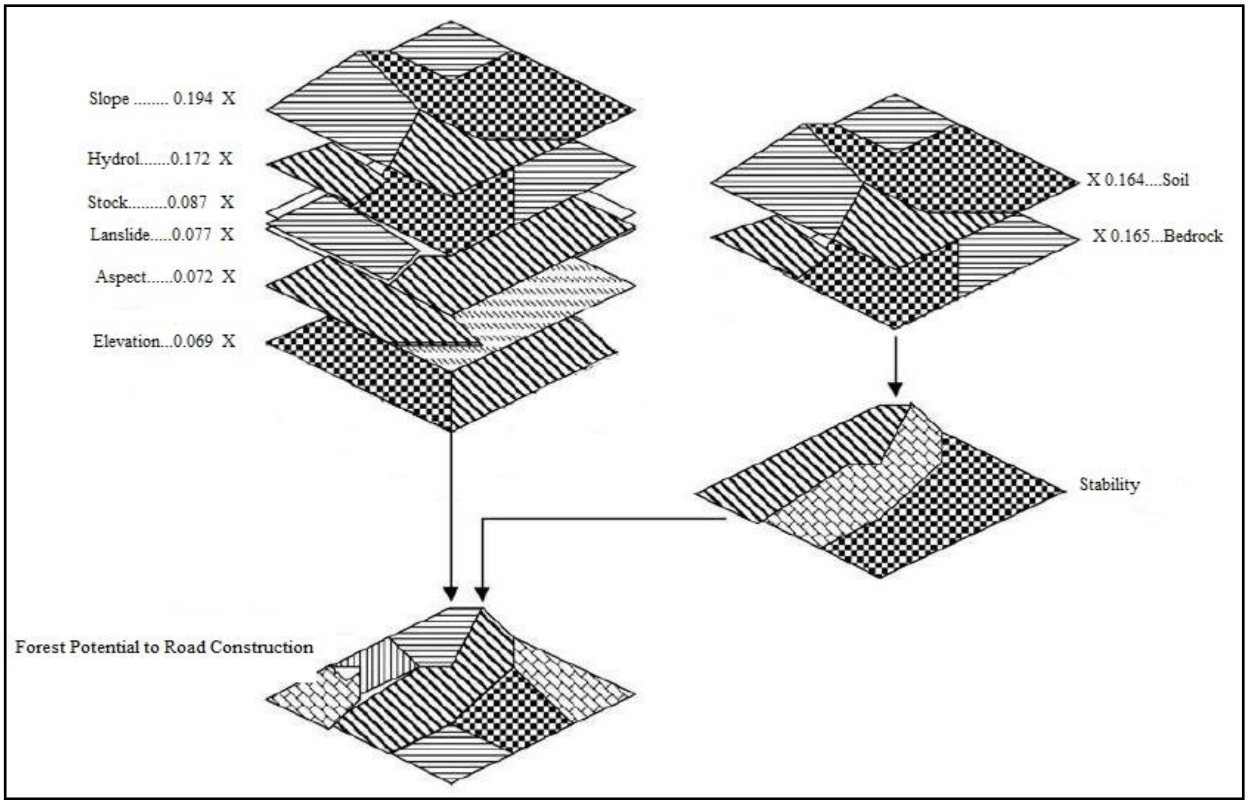


Figure 3. GIS layers used for produce forest potential to road construction

2.2.4. Planning the forest road network

Two roads were designed to evaluate the existing road. The first road was designed through the traditional method. The second road was planned through the use of RoadEng® Software. RoadEng® Forest Engineer version is especial Canadian software for planning and designing forest operations and forest roads, consisting of three modules [51]: Survey/Map, Terrain and Location.

To compare the existing road network and the RoadEng® based network, the percentage of their crossing from stable areas owing to the stability map was used as the judgment criterion.

2.2.5. Comparison and evaluation of roads

In this step, the map of both existing and planned forest roads network were overlapped with the FPRC map and the percentage of passage of each road (i.e. existing and RoadEng® proposed road) through the four potential classes of stability was calculated. The classes were namely, high, moderate, low, and unstable. The percentage of each road network located in the mentioned area was then measured and compared with others. Road density was obtained using the (2) formula and road spacing was determined theoretically using the (3) formula as follows Backmund, [48]:

RD=road length (m)/district area (ha) (2)

RS=10000/RD (3)

in which RD was Road Density and RS was Road Spacing.

3. Results and Discussion

GIS-based MCDA and RoadEng technique was employed as a new approach to produce the forest road network planning. In this point, AHP was chosen over wide variety of MCDA techniques to produce forest road network planning of the area.

Calculation of the factor weights has a crucial role in the production of produce forest roads construction maps when applying the MCDA technique. The eigenvector method based on pairwise comparison was employed for this purpose, in that each factor was ranked considering its importance by scale ranging from 1 to 9. After the pairwise comparison matrix was formed, weights of the factors were calculated (Figure 4).

In AHP method, inconsistency ratio (IR) is used to indicate the probability that the matrix judgments were randomly generated. IR value of 0.1 or less is a reasonable level of consistency [29]. If the IR value is greater than this level, inconsistency of judgments within that matrix occurs, and the evaluation process should revise the original values in the pairwise comparison matrix.

In this study, the IR value for the pairwise comparison matrix was estimated as 0.07, confirming a valid consistency. The result from evaluating the factors with 0.07 incompatibility coefficients showed that the slope and hydrographic network, due to having the greatest coefficients, had the highest importance in the forest road planning. The factor with the smallest coefficient, elevation, had the lowest importance in road planning (Figure 4). A Study by Samani et al. [39] on forest road planning in mountainous area showed that slope was one of the main factors as well to be considered among the four factors listed.

The results of using the Nilsen method to prepare stability showed that 5175 ha were covered by stable areas. Finally by overlaying the slope and bedrock maps, the stability map was produced using four classes. The classes were namely; high, moderate, low, and unstable (Figure 5). Thereby the was generally favorable conditions for forest road planning. The ground stability map, which demonstrated a 56 % high stability region, provides the possibility of road planning with a desired stability. Viewpoint of slope, 70% of the region has a slope of less than 71%, so forest road planning could be performed at a high level of assurance.

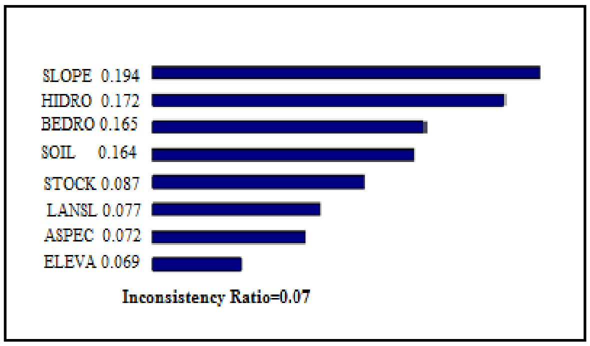


Figure 4. Factor weights and inconsistency ratio of forest road planning

By overlaying the weighted maps of affecting factors, a map of forest road construction (FPRC) was produced. The later map showed three classes: high, moderate, and low road construction compatibility. It was the planning of the road map by RoadEng® program. Figure 6 shows that the planned road covers the high potential areas for road construction. It can be seen that planned road network overlays some sections of the existing roads. In the present study, the roads were planned in regions with high accessibility and stable ground

The results of this study showed that planned roads were mainly located high and moderate roading capability (93,5%), distributed on sandy loam and andesite-basalt bedrock (45%) and accessible region (slope < 45%) comprise 26 % of study area. Moreover, 89% of the existing roads networks were located in high and moderate roading ability regions, 33% in high stability regions, 27% in regions with sandy loam and andesite-basalt bedrock and finally, 18% in areas with accessibility to a region with a ground slope of less than 45%. Therefore, the existing road network, these figures, with regard to the planned road networks in environmental parameters show that the disadvantaged.

The planned and existing roads network each provided an accessibility of 85% for the logging planning area, but the existing roads network with 93 km length, 17.9 m/ha road density and 558m road spacing and the planned roads network with 44 km length, 8.9 m/ha road density and 1123m road spacing.

This shows that the planned road network was economically superior to the existing roads network, because it achieved 85% acceptable accessibility with less road length. Table 1 shows the comparison of planned and existing roads network with regards to effective parameters in planning forest road networks.

Today, forest managers and foresters should be more aware of the design and construction of forest roads and consider the design of road networks carefully. This is because of the fact that most of the costs of forest management are related to road construction and that the environmental effects of roads are irrecoverable [40].

Forest road network planners often need to make a decision between several objectives. Therefore, one of the most useful models could be the GIS-MCDA method. The use of GIS-MCDA qualitative and quantitative criteria can be employed and incorporated into decision making [35-43]. Furthermore, GIS and RoadEng® software systems provide the basic tools for forest road network planning. GIS and RoadEng® offers a number of advantages compared to the traditional troublesome and time consuming methods.

This study tested a new method of linking traditional and more advanced road network planning, as it proposes the combination of two methods. [17,41,42,21] Naghdi and Babapour, [43-52] also suggested that applying the GIS technique is preferential in comparison to the traditional method. The technical accuracy aspect of the proposed GIS-AHP method was at a higher than that of the traditional method.

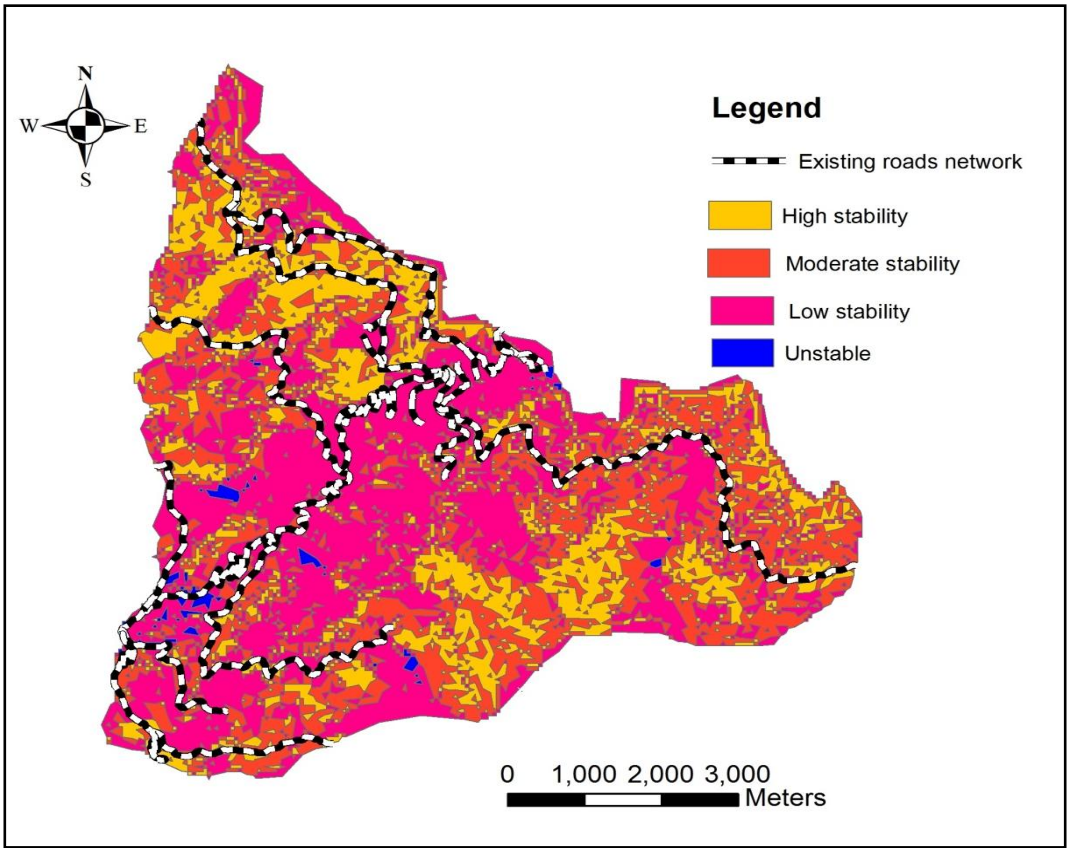


Figure 5. The ground stability map of study area

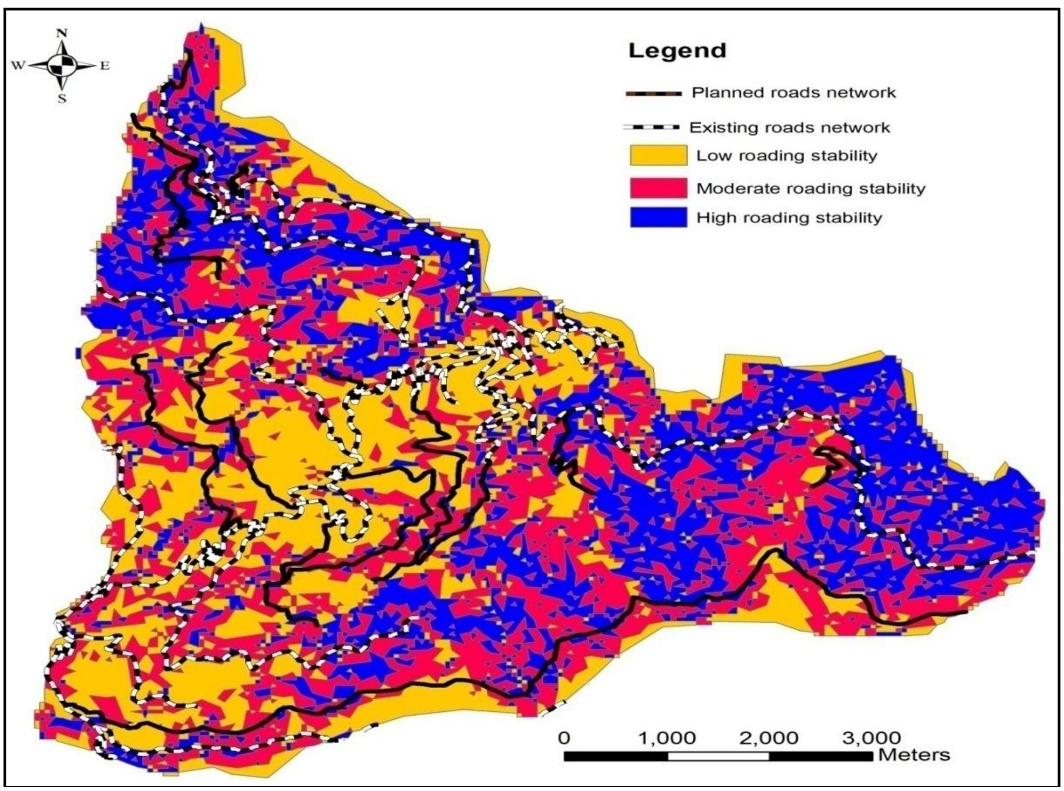


Figure 6. Forest roads construction stability map (planned and existing roads network)

Table1. Comparison of planned and existing roads network with regards to effective parameters

Parameters	Forest roads network	
	Planned roads network	Existing roads network
Length of roads (km)	44	93
Road density (m/ha)	8.9	17.9
Spacing of roads (m)	1123	558
Percentage of roads length that are located in regions with high and moderate forest potential to road construction	93.5%	89%
Percentage of roads length that are located in high stability regions	44%	33%
Percentage of roads length that are located in regions with sandy loam and andesite-basalt bedrock	45%	27%
Percentage of roads length that are located in regions with the ground slope of less than 45%	26%	18%
Accessibility for the logging planning area (Accessible areas for logging)/ total areas*100	85%	85%

Using GIS to design and evaluate forest road variants was very effective [43,44) and not only does it lead to the simplicity of using AHP method [45], but it can also be a good help in computing and analyzing data. It was proposed to be a good method to use in forest road network designing.

In the current study, the most important layers were slope, hydrographic network, geology and soil. Naghdi and Babapour [43] stated that the most important layers for road construction map were stability layers. Their results are similar to those of the current study. These results indicated that slope, hydrographic layers, bedrock and soil texture were more important than other layers from an expert's point of view. According to Kunwoo's studies [46] on the low slopes of the orientation of forest roads in mountainous regions and reduced the cost of excavation resulting in a reduction of causes will create small trenches. In this study, it was intended that the planning of forest roads would be done by following the slopes and accessibility for appropriate covering forest in the areas with high potential and value similar to the studies of Audery [47-43].

4. Conclusions

The results of this study present that GIS-based MCDA and RoadEng techniques are one of the most valuable tools to locate and identify the mountainous area for forest road planning.

This study has considered forest road network planning the MCDA-GIS-ROADENG-based method. The principle of planning forest road networks was to pay attention to slope, aspect hydrographic network, stock growth(m^3/ha), soil, bedrock, landslide susceptibility and elevation. Considering all the above factors simultaneously was not possible in the traditional approaches of roads network planning. In the GIS-MCDA-ROADENG environment, all of the mentioned data layers can be analyzed simultaneously at a lower cost and short time.

These results suggest that multi-criteria evaluation method can be more accurately to design forest road planning in mountainous area. The results showed that this methodology can be more helpful and road network can be planning quickly with less cost than traditional method.

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Corresponding Author:
Erhan Çalışkan,
Department of Forest Engineering, Faculty of Forestry, Karadeniz Technical University, 61080, Trabzon, Turkey.
E-Mail:erhan_caliskan@yahoo.com

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