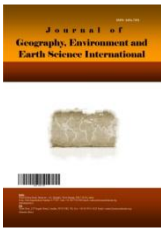

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GIS Based Planning of Forest Road Alignment in Periyar Tiger Reserve, Kerala, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In hilly places, constructing and building forest roads requires a variety of economic and environmental criteria. To develop a solution that minimize construction, maintenance, and adverse environmental effects, road management must take into account as many alternative alignment options as they can. The idea of this research was to plan the network of forest roads in the Periyar Tiger Reserve's mountainous region using Geographic Information Systems (GIS) based on Multi-Criteria Decision Analysis (MCDA). These techniques were applied using the study area's slope, aspect, Elevation, NDVI, drainage and susceptibility to landslides datasets. In addition, the road network created using the GIS-MCDA approach was contrasted with the existing road networks. The key elements that affect the road network in the research area were found, and the necessary maps were produced and categorized. The maps were graded using MCDA to determine the weight of both useful aspects as the next step in determining the significance and role of the aforementioned elements in the cost of road building. Second, using the Arc GIS 10.4 weighted overlay analysis tool, a forest potential map for road building was created by overlaying the weighted maps of the influencing elements. Thirdly, the competence of a map was divided into Six categories: very high, high, moderate, low, very low and Restricted roading Suitability. Finally, using

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a weighted overlay method to combine the road network and road planning potential map, the existing road network was analyzed. The findings of this study indicated that the majority of existing roads were located in high and moderate road Suitability. A small percentage was located in low road Suitability, which can be taken into account for alignment. These results suggested that the design of forest road planning in hilly areas can be more precisely accomplished using the multi-criteria evaluation method. Similar method as used in this study can be applied to other forested sites.

Keywords: GIS; MCDA; forest road network planning; Periyar Tiger Reserve.

1. INTRODUCTION

Forest roads are essential for forest management, transportation of wood raw materials, protection, and forestry activities in mountainous areas. It is difficult to incorporate technical and environmental concerns into manual road planning. Geographical Information System (GIS) capabilities have recently enabled concurrent information management based on important factors in road planning seeking rapid assessment of roads [1-4]. One of the most important factors in forest road network planning is the cost of road construction and maintenance during the initial route location in the field. Because of the close relationship between the costs of road construction, maintenance, and soil and bedrock stability, it is necessary to locate the roads on more stable terrain to reduce the total costs of road construction and maintenance. The road design and construction process is one of the most costly and damaging activities in forestry, as evidenced by slope failures and mass movement [5]. To mitigate these negative effects, forest road managers must seek ways to expand road networks with the improved environmental sustainability and public acceptance of road construction activities [2,6].

To minimize the extent of these impacts, environmental impacts of road construction must be assessed prior to the road construction. Previously, most of forest road design criteria were based on existing timber harvesting sites at the lowest possible cost [7–12]. The process of designing and analyzing a skid trail was carried out using a GIS method in Russia and concluded that using GIS as a decision-making system can be a cost-effective method for providing appropriate alternatives in forest road locating. Multi-criteria analysis techniques are well known as decision-support tools for dealing with such complex decision-making processes where technological, economic, and environmental factors must all be considered in order to obtain an overall assessment of the decision alternatives [13–17]. The analytic hierarchy process (AHP) has become one of the most widely used multi-criteria decision support systems to assist users by breaking down these complex decisions into a hierarchy [18–22].

The combination of AHP in a GIS environment allows for the combination of different types of information at different scales. The manual performance of such analysis was not only difficult but also time consuming. Unlike manual forest road planning, AHP allows us to use the ideas of various experts, calculate incompatibility coefficients based on quantitative and qualitative criteria [3]. The AHP method, with the appropriate features and weights, is frequently the best choice in obtaining accurate results. Indeed, the AHP method assists decision makers in prioritizing goals and developing sets of appropriate criteria. The method also assists in the systematic and logical preparation of evidence for the selection of the best and most suitable road network alternative from the multi-criteria analysis [23]. In spite of this, the GIS-based Multicriteria Decision Analysis (MCDA) has not been widely used for forest road planning in Kerala. Therefore, the aim of this study was to design the forest road network using in mountainous area of Periyar Tiger Reserve (PTR). These methods were employed using slope, aspect, terrain, Normalized Difference Vegetation Index (NDVI), river, and landslide susceptibility maps of the study area. Moreover, road network generated by GIS-MCDA method was compared with existing road networks.

2. MATERIALS AND METHODS

2.1 Study Area

This study was conducted in the Eravangalar section of the Periyar Tiger Reserve in Kerala, a forest section covering approximately 15.46 square kilometers of forest area in the Periyar East Division of the Reserve. The coordinates were lies in between 9°35'44.03"N &

9°34'18.09"N and 77°18'22.80"E & 77°16'40.89"E. The study area is located in a mountainous area and has a slope ranging from 0% to 80%. The relief is very irregular, with elevations ranging from 900 to 1900 m. The average annual precipitation is 1150 mm, with the wettest months being July and August. According to Forest Records, the road's name is Eravangalar-mavady road. Fig.1.

2.2 Data Used

2.2.1 ALOS PALSAR DEM

The ALOS-PALSAR (Advanced Land Observing Satellite Phased Array L-band Synthetic Aperture Radar). ALO-S/PALSAR was launched in 2006 by the Japan Aerospace and Exploration Agency (JAXA). The ALOS-PALSAR was operational until May 12, 2011. The satellite has provided Earth observation data with high resolution for topographic mapping, disaster and environmental surveillance, and climate change investigation. ALOS was launched in a sun-synchronous orbit and circled around the Earth every 100 minutes, 14 times a day. ALOS-PALSAR returned to the original path (repetition cycle) every 46 days. The inter-orbit distance was about 59.7 km at the equator. ALOS-PALSAR has a spatial resolution of 12.5 m at 23.62 cm (1.27 GHz) wavelength with HV polarization and angle of incidence 38.7°. which is used to derive all layers for this analysis.

2.2.2 SENTINEL-2 DATA

SENTINEL-2 is a European wide-swath, high-resolution, multispectral imaging mission. The full mission specification of the twin satellites flying in the same orbit but phased at 180°, is designed to give a high revisit frequency of 5 days at the Equator. SENTINEL-2 carries an optical instrument payload that samples 13 spectral bands: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution. The orbital swath width is 290 km. The main objectives of this mission are systematic global acquisitions of high-resolution, multispectral images aligned to a high revisit frequency, continuity of multispectral imagery provided by the SPOT series of satellites and the USGS LANDSAT Thematic Mapper instrument and observation data for the next generation of operational products, such as land-cover maps, land-change detection maps and geophysical variables. These high-level objectives, determined after consultation with users, will ensure that SENTINEL-2 makes a significant contribution to Copernicus themes such as climate change, land monitoring, emergency management, and security. (ESA). Which is used for derive NDVI layers.

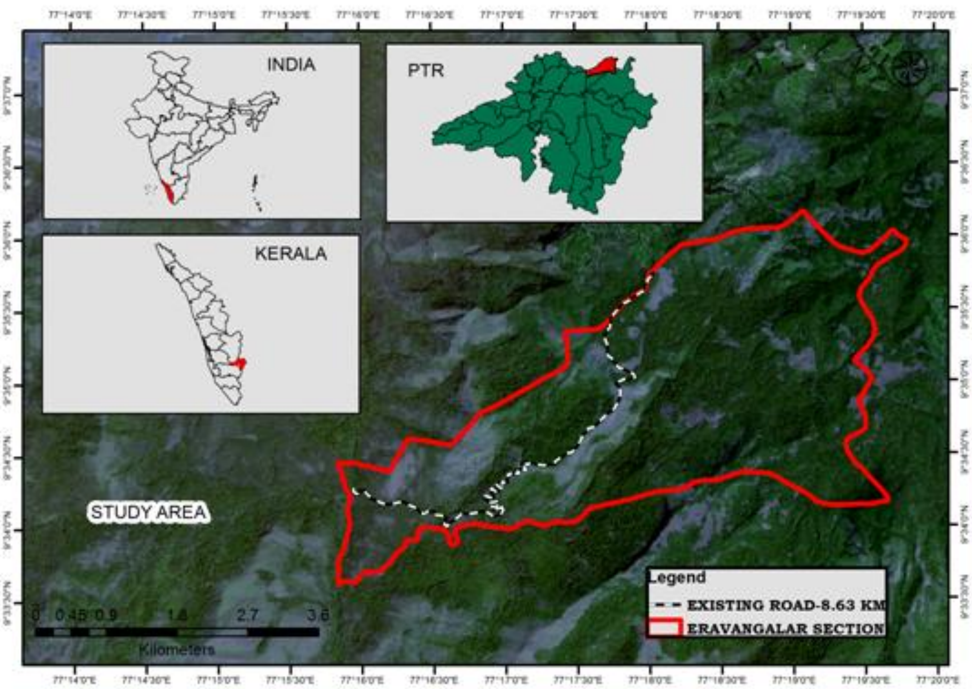

Fig. 1. Study Area -Eravangalar -Mavady Road

Table 1. Details of satellite Data

Sl.no	Satellite	ID &Date of acquisition	Source
1	Sentinel-2	L1C_T43PFL_A029903_20210314T051944 & 14-3-2021	European Space Agency
2	ALOS PALSAR	AP_05086_FBS_F0150_RT1 &3-3-2018	Japan Aerospace Exploration Agency

2.2 Methods

In this study, thematic layers associated with slope, river, aspects, NDVI, landslide susceptibility, and terrain, which can influence forest roads, were considered in the forest road network planning. Forest potential map of road construction was prepared by using these layers and overlaying them. The analyzed data were prepared using ArcGIS 10.4 software. The effective factors were specified by field trips and by 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, slope, aspect, and elevation maps were produced. NDVI, Stream buffer was prepared by using ArcGIS tools. landslide susceptibility data, which were downloaded from open-source data portals (landslide Susceptibility -DDMA Idukki, Kerala).

2.3 Input Parameter

2.3.1 Slope

Slope is one of the main factors that needs to be considered in the planning forest road network. Slope 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 units of percentage using the ALOS/PALSAR DEM (12.5 m) of the study area. The slope map was classified into three classes: 0-45%; 45-66%; and >66% (Fig. 2).

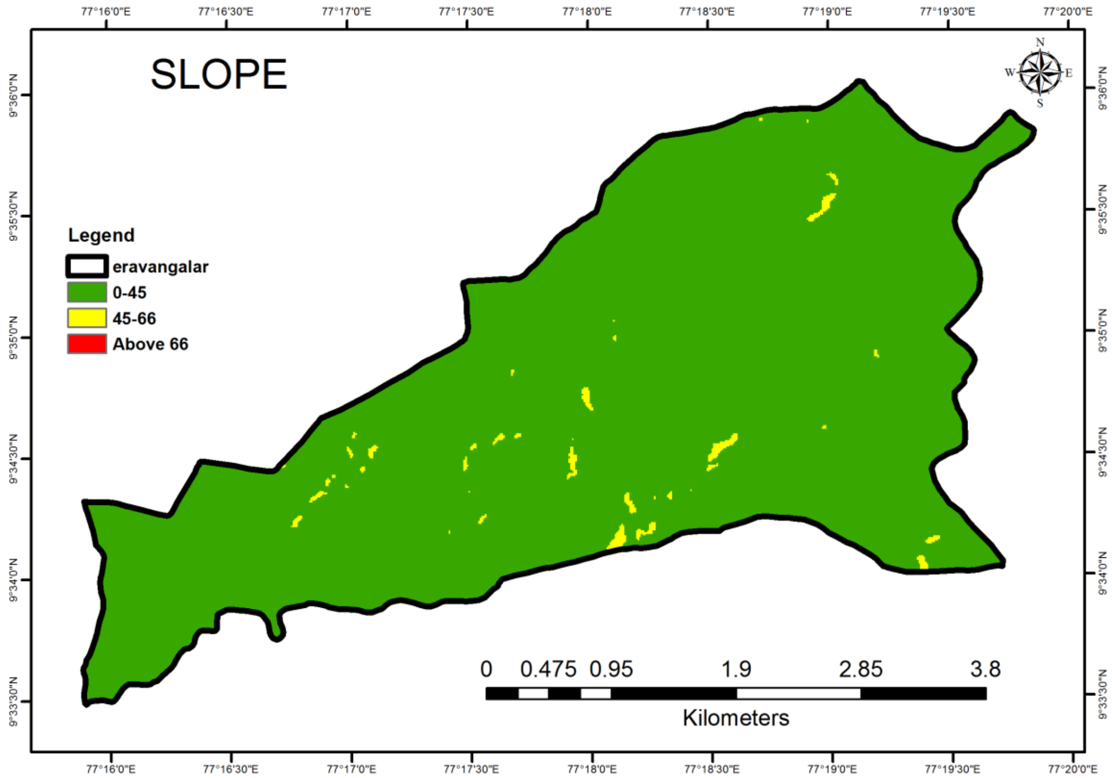

Fig. 2. Slope Map

2.3.2 Aspect

Aspect associated parameters such as exposure to sunlight, drying winds, and rainfall are important factors in the forest road design. 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 was characterized as north, east, south, and west in this study (Fig. 3).

2.3.3 Elevation

Elevation (height above the sea level) is known by its effects on biological and natural factors. The elevation map of the study area was divided into four classes: 806-1036 m; 1036-1290 m; 1290-1500 m; and >1500 m) (Fig. 4).

2.3.4 NDVI

The normalized difference vegetation index (NDVI), which is derived from remote-sensing data, is closely linked to drought conditions. To determine the density of green on a patch of land, the distinct colors of visible and near-infrared sunlight reflected by the plants are observed. The range of NDVI is −1 to +1. Higher value of NDVI refers to healthy and dense vegetation. Lower NDVI values show sparse vegetation. The NDVI map (Fig. 5) was prepared by using Sentinel-2 images acquired in band 8 (near-infrared) and band 4 (red). Dense forest can be restricted for this analysis.

NDVI = ((BAND8 – BAND4)/ (BAND8+BAND4))

2.3.5 River

Streams may adversely affect 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) (Fig. 6).

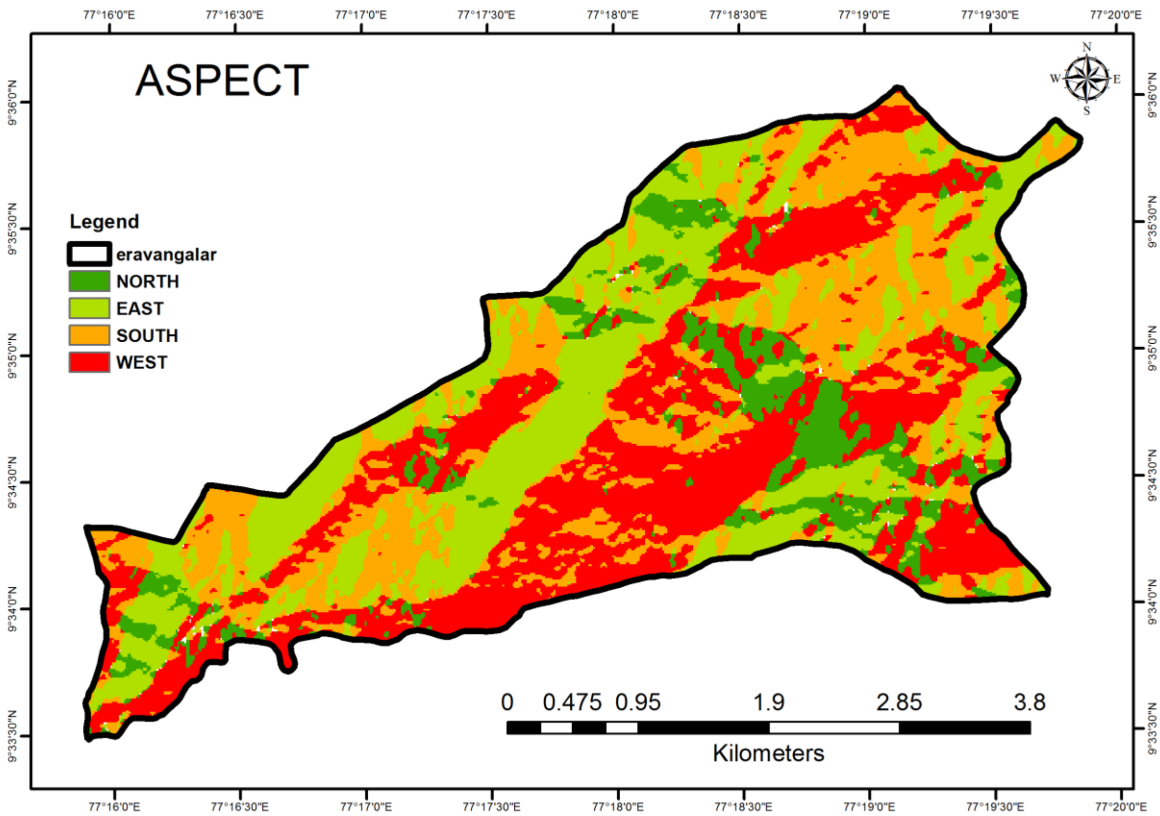

Fig. 3. Aspect Map

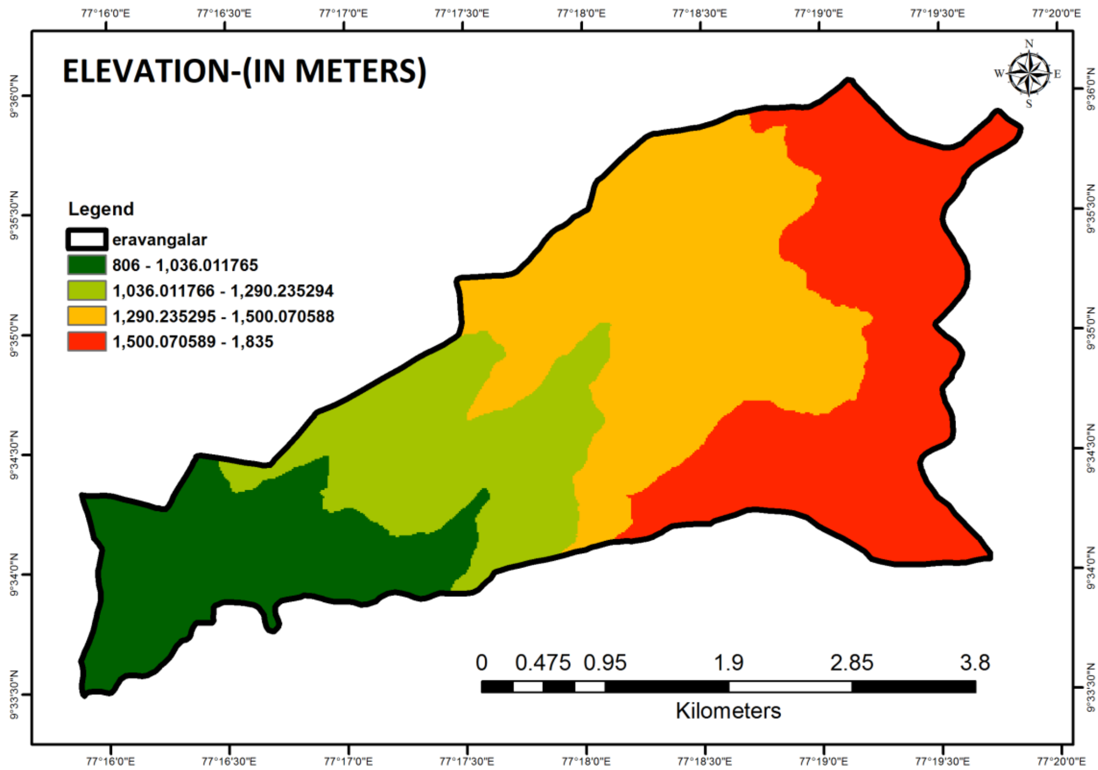

Fig. 4. Elevation map of the study area

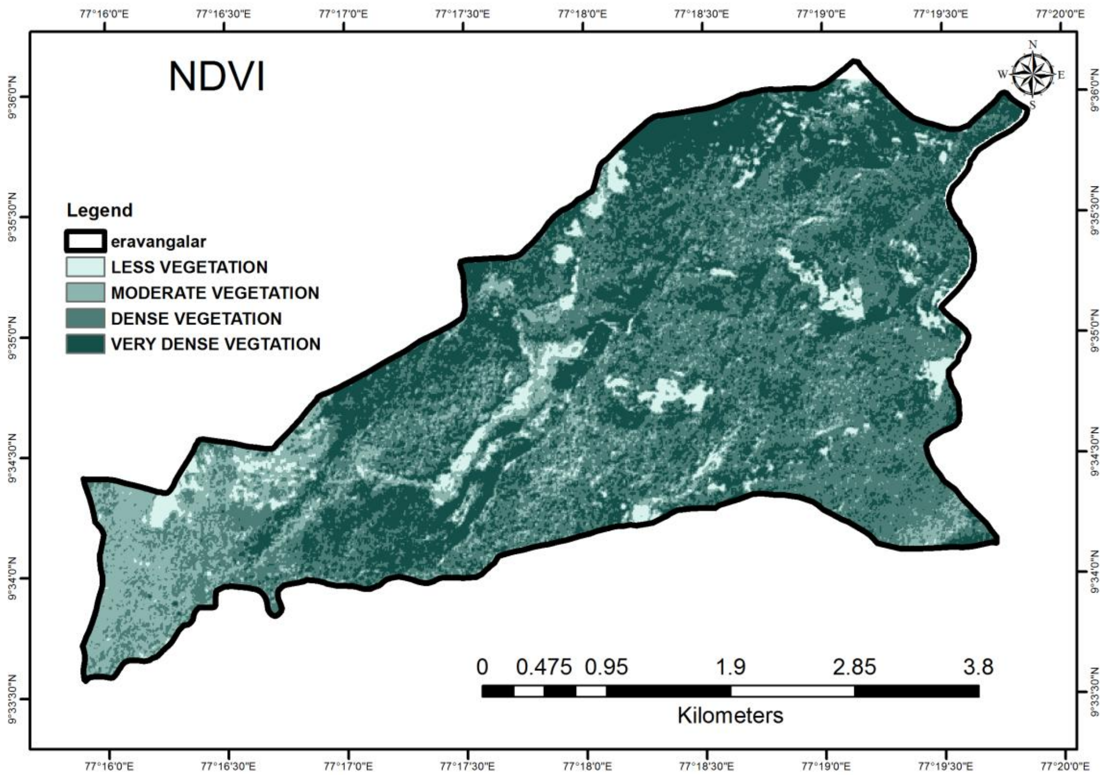

Fig. 5. NDVI map of the study area

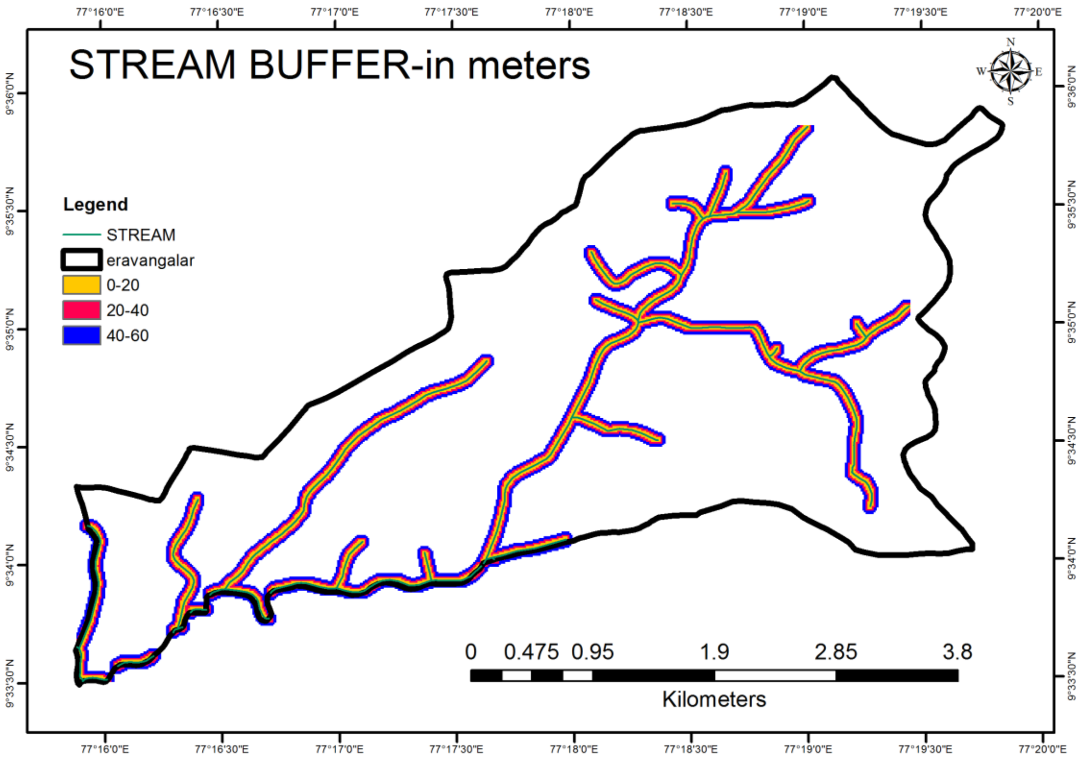

Fig. 6. Buffer stream map of the study area

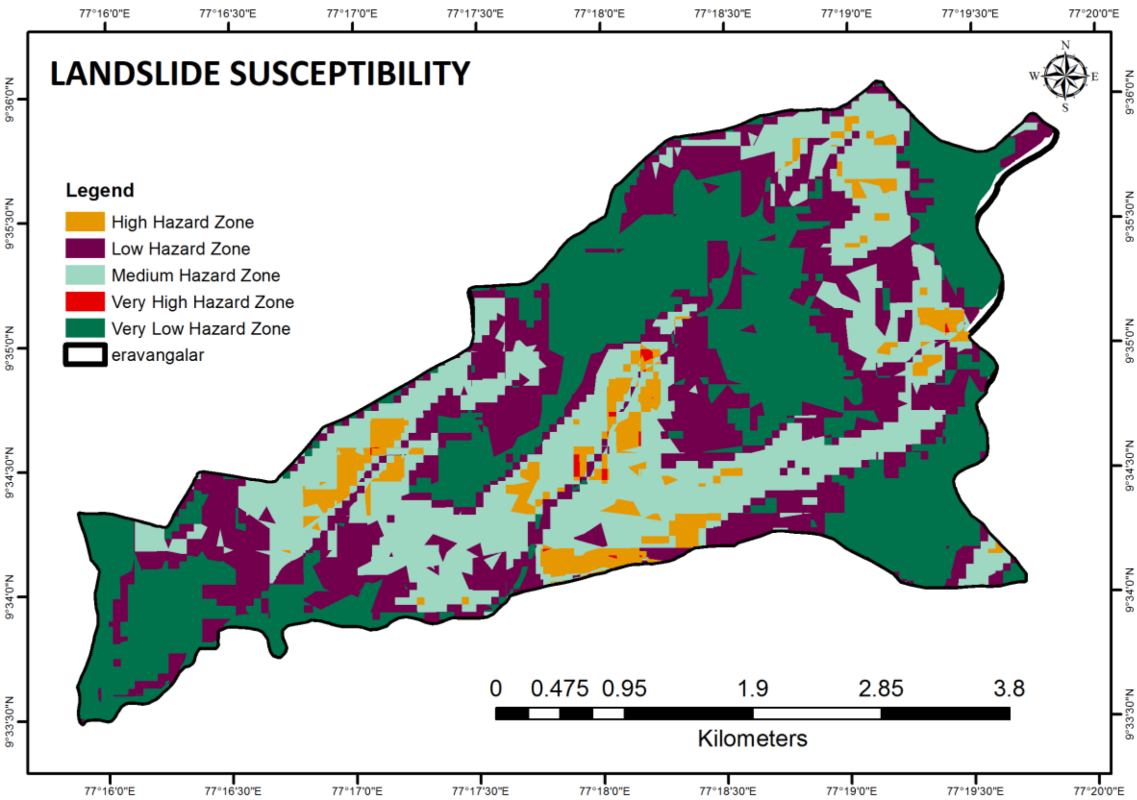

Fig. 7. Landslide Susceptibility map of the study area

Table 2. Distribution of attribute weightage and rating

Variables	Weights	Ranks	Classes
NDVI	10	1	Less vegetation
		2	Moderate vegetation
		3	Dense vegetation
		Restricted	Very dense vegetation
Slope	30	1	0-45%
		2	45-66%
		3	above 66%
Aspect	20	1	North
		2	East
		3	South
		4	West
Elevation	10	1	806-1036 m
		2	1036-1290m
		3	1290-1500m
		4	above 1500 m
Stream Buffer	10	3	0-20 m
		2	20-40 m
		1	40-60 m
Landslide Susceptibility	20	1	Very low
		2	low
		3	Very high
		4	high
		5	medium

2.4 Landslides Susceptibility

Natural landslides may also be present and may cause instability of the road itself, road cuts, and embankments. Consequences of instable road cuts and embankments may be failure of the road, be dangerous, and may make the road unusable. 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 Five classes (High, Low, Medium, Very High, Very Low). (Fig. 7)

GIS-based MCDA is a process that transforms and combines geographical data and value judgments to obtain information for decision making. Although several methods exist for estimation of decision criteria in the MCDA, the analytical hierarchy process (AHP) developed by Saaty [24] 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) [23]. 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 rated 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 according to the selected criteria (Table 2). The raster layers have been given weights based on the requirement and then analyzed by the weighted overlay tool in ArcGIS10.3. These attributes/layers are overlaid and a single layer composite is generated by assigning weight values to each attribute. After that, a forest road potential map was prepared with four classes (low to very high). Finally, the map is validated with actual existing road.

3. RESULTS AND DISCUSSION

GIS-based MCDA 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. Each factor used has been identified and compiled by priority ranking.

Data integration was then performed to generate a value map. Each parameter is based on a weightage and the summation of the weight must be 100%. By overlaying the weighted maps of affecting factors, a map of forest potential road construction (FPRC) was produced (Fig.8). The later map showed six classes: very high, high, medium, low, very low and restricted road construction compatibility.

Existing road was overlaid in to that potential map and the road laid on low roading capability (critical locations) can be identified for further alignment., which is useful to forest managers for planning of forest road alignment. We prepared a planned road with the help of a suitability map. The planned road meets all safety standards, particularly landslide susceptibility and slope. The majority of the planned road is located in a low landslide hazard zone and has a slope of less than 45 degrees, allowing for easy vehicle access to the forest road. Many roads will be damaged during the flooding period, but in our analysis, we include the stream as one of the covariates, as a result of properly mapping the stream factor, unnecessary road damage due to flooding can be avoided. Planned and existing road statistics are given in the (Table .3.) and Fig. 9.

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 irretrievable [25].

Forest road network planners often need to make a decision between several objectives. Therefore, one of the most useful models' is could be the GIS-MCDA method. The use of GIS-MCDA qualitative and quantitative criteria can be employed and incorporated into decision making [26-31]. Furthermore, GIS systems provide the basic tools for forest road network planning. It offers a number of advantages compared to the traditional troublesome and time-consuming methods. [3] 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 higher than that of the traditional method.

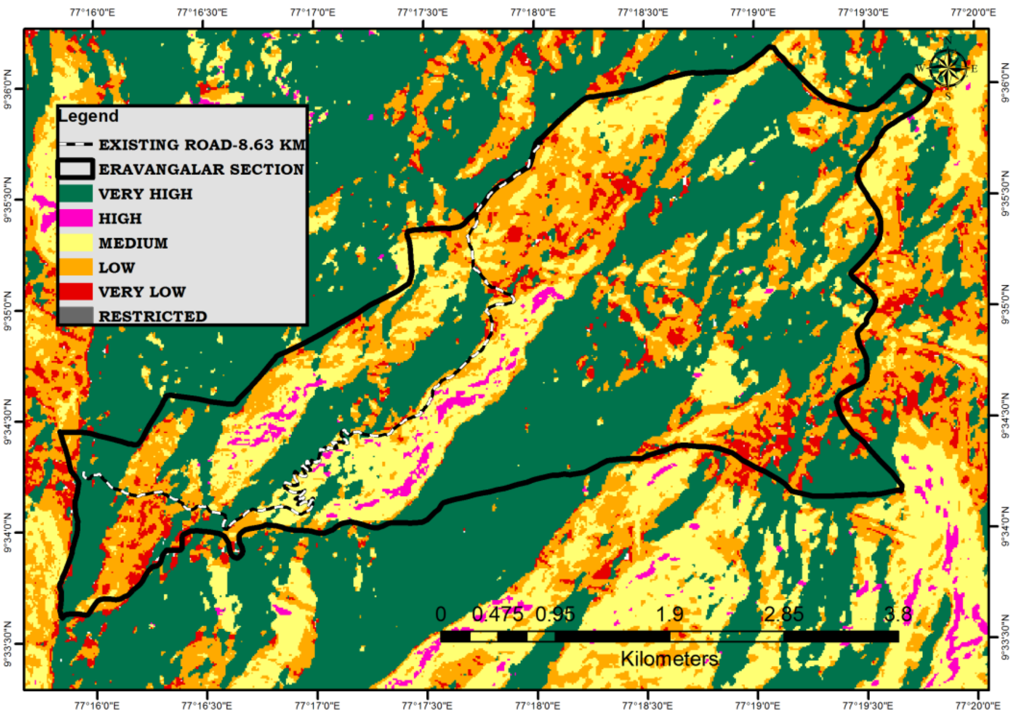

Fig. 8. forest road potential construction map

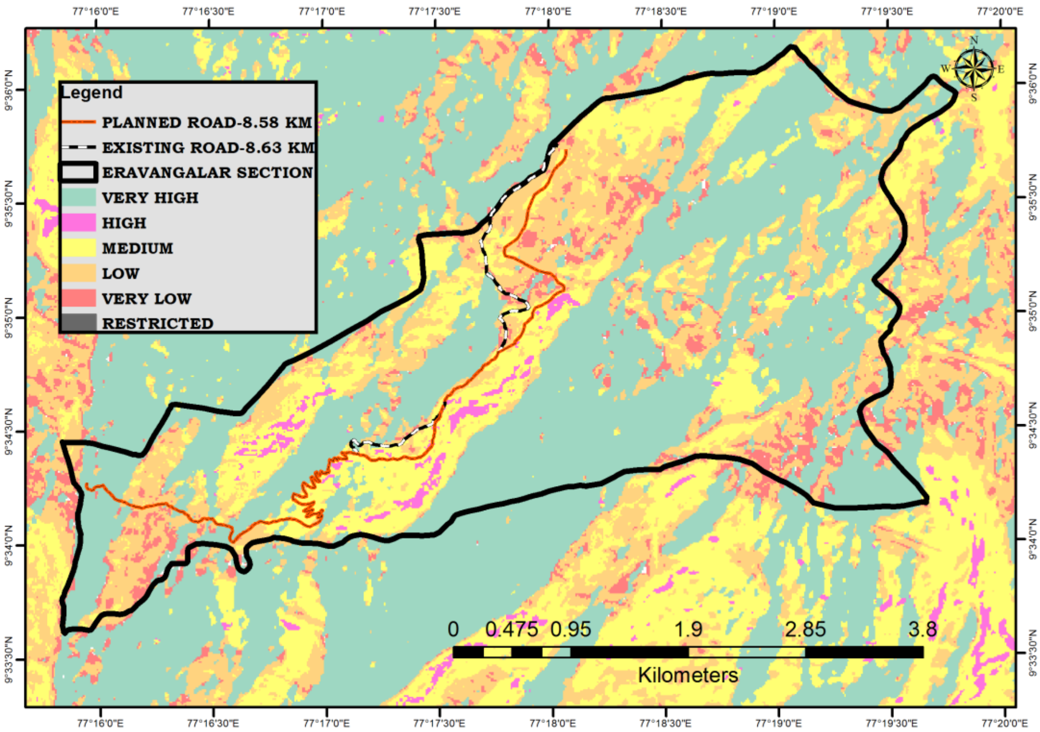

Fig. 9. Forest roads construction stability map (planned and existing roads network)

Table 3. 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)	8.58	8.63
Spacing of roads (m)	3	3
Percentage of roads length that are located in regions with medium forest potential to road construction	70	50
Percentage of roads length that are located in regions with the ground slope of less than 45%	90	80
Percentage of roads length that are located in regions with landslide susceptibility of Very low hazard zone	70	60

Using GIS to design and evaluate forest road variants was very effective [3,32] and not only does it lead to the simplicity of using AHP method [33], but also 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.

4. CONCLUSIONS

The findings of this study indicate that the GIS-based MCDA technique is one of the least time-consuming methods for locating and identifying mountainous areas for forest road planning. This study has considered forest road network planning using the MCDA-GIS-based method. The principle of planning forest road networks was to pay attention to slope, aspect, stream buffer, NDVI, landslide susceptibility and elevation. Considering these factors simultaneously was not possible in the traditional approaches of roads network planning. In the GIS-MCDA-environment, all of the mentioned data layers can be analyzed simultaneously at a lower costs and short time. These results suggest that multi-criteria evaluation method can be more accurately used to plan forest roads planning in mountainous areas. The results showed that this methodology can be more helpful and road network can be planned quickly with less cost than traditional methods.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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