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Predicting the earthwork width and determining the annual growth loss due to forest road construction using artificial neural network and ArcGIS

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ABSTRACT: The area of forest destruction as well as the annual growth loss due to road construction before constructing a road was predicted. To do this, road cross sections of 88 points along the 10 km proposed road were predicted using Multilayer Perceptron Neural Network with two input parameters of hillside slope and rock share within MATLAB software. Then according to the predicted width, the area of road earthwork as well as the area of roadside with a 10 m width was calculated in ArcGIS software. Finally, by overlaying the inventory network layer on the road map and by knowing the annual growth (m^3) for each plot the growth loss of the area of road earthwork was calculated and one-third of the annual growth increment was considered to calculate the growth loss of the roadside. According to the results, for the construction of a 10 km long road in the region, 12.98 ha of forest area is destructed due to road construction, of which 5.36 ha is destructed resulting from earthwork operations and 7.61 ha occurs in the roadside and its growth is influenced by road construction. With the construction of the road, in total, 32.606 m^3 of growth will be lost annually, of which 22.221 m^3 is due to road earthwork that is completely removed from the forest annual growth cycle and 10.384 m^3 of the growth loss belongs to the roadside which is decreased resulting from road construction.

Keywords: area of road earthwork; hillside slope; roadside; rock share

This study was carried out at the Training and Research Forest of Tarbiat Modares University, watershed 46, Mazandaran province, Iran. Forest roads are the most essential component of scientific forestry which play an important role in timber transportation as well as in the use of other forest services (Majnounian et al. 2012). Despite the numerous undeniable advantages, constructing roads requires strip cuttings and harvesting trees on the route, so it causes extensive long-term changes in terms of entering sunlight, moisture, as well as soil physicochemical properties because forest trees are harvested in micro- and meso-scales creating a corridor and diversity and density of plant communities change depending on the magnitude and intensity of changes (Najafi et al. 2011). Regardless of the trees which are cut and completely eliminated from the production cycle due to earthworks operations, a certain width of the road is always imposed at risk of the establishment of native invasive species as well as herbaceous species because of their ability to propagate and use of bright light (Aikens et al. 2007) so the production of wood decreases. Olander et al. (1997) studied the effects of damage caused by road construction in a subtropical forest and found changes in the species composition at 5–10 m from the roadside. The results obtained by Godefroid and Koedam (2004) also demonstrated the impact of forest routes on adjacent vegetation and an increased number of indicator species of destruction on the roadsides of beech forests in central Belgium. Thus in designing a forest road, the goal is that while having the most suitable amount of forest transportation network, the least adverse effects on ecosystems should exist, and changes in the species composition and the annual growth loss of woody species resulting from road construction should be at a minimum level.

To achieve this, predicting the surface area of the forest that will be influenced by road earthwork operations as well as predicting the annual growth loss due to constructing a road before its construction it could be effective in selecting a more appropriate design alternative and decreasing the destruction area and reducing economic costs and environmental damage. In the mountain forests, natural slope of the hillside as well as rock share are important natural factors influencing the road cross section thereby the road earthwork area, thus these factors are used in estimating the earthwork operations (Potočnik 2003; Peyrov et al. 2014). Thus, by knowing the forest annual growth, the annual growth loss due to the road construction can be calculated before performing road construction operations. Today, in designing and constructing roads, problems and deficiencies of traditional methods on the one hand, and the change in forest management objectives and the introduction of environmental and economic criteria have resulted in the application of new methods of higher capabilities, so it has led the designers to use the computer and then GIS (geographic information system) (Sarikhani, Majnounian 2012). A possibility of designing and evaluating the forest road network variants using GIS and field investigations (Alizadeh et al. 2011), determining the proper method of preliminary forecasting of mountain and forest roads using GIS (Raafatnia et al. 2006), planning forest road alignment using the shortest path algorithm and geographic information system (Imani et al. 2012), and forest road network planning based on environmental, technical and economic considerations using GIS and analytic hierarchy process (Shahsavand et al. 2011) are among studies that have been carried out on forest roads by using GIS.

Peyrov et al. (2016) studied the effects of physiographic parameters on the road cross section in mountain forests. Results showed that the parameters including hillside slope and rock base had a significant effect on the cross section.

Kokmila et al. (2009) mapped the forest functions using GIS at a plateau area, Laos. In this study they presented the process of classification of forest functions for improving forestry agriculture and livelihood standard in Champasak province, Bolivian plateau area. It is arable land supporting agriculture and protecting watersheds. Geographic information system was used to classify and map three functions, namely conservation forest, protection forest and production forest. These functions were linked for planning watershed management, improving forestry, agriculture and water supply system in rural forest areas.

Karlsson et al. (2006) described a decision support system called RoadOpt for the planning of forest road upgrading. A case study from a major Swedish company is presented. In this study the planning horizon is about one decade. The system uses a GIS-based map user interface to present and analyse data and results. Two important modules are the Swedish road database, which provides detailed information about the road network, and an optimization module consisting of a mixed integer linear programming model.

Potočnik (2003) assessed the rock base and hillside natural slope as some factors influencing the road formation width, and results showed that the road formation width could increase up 80% more in a steeper terrain (compared to a gentle terrain slope) and 20% less on a solid rock base regardless of the terrain slope. It varies between 5.4 m (solid rock base, gentle slope) and 11.4 m (soft rock base, steep slope).

In the case of modelling and forecasting methods, numerous techniques in different sectors of forestry practice have been employed and parallel to the previous conventional models today a newer method of artificial neural network has successfully been used for prediction. Predicting the road cross section of forest roads using an artificial neural network (Peyrov et al. 2014), tree density estimation of forests by terrain analysis and artificial neural network (Ghanbari et al. 2009), applications of radial basis neural networks for area forest (Castellanos et al. 2007) and mapping the tropical forest structure in southeastern Madagascar using remote sensing and artificial neural networks (Ingram et al. 2005) are among researches conducted in this area.

The main purpose of this study was to estimate the forest growth loss resulting from road construction using GIS and artificial neural network before road construction which could significantly influence the environmental and economic evaluation of different variants of forest road network.

MATERIAL AND METHODS

Study area. The study area is located at the Training and Research Forest of Tarbiat Modares University, watershed 46, Mazandaran province between 51°41'05'' to 51°48'12''E and 36°29'14'' to 36°33'18''N with minimum height and maximum elevation of 140 and 1,720 m, respectively (Fig. 1).

Preparation of informational layers. Maps of hillside slope and rock share: contours of topo-

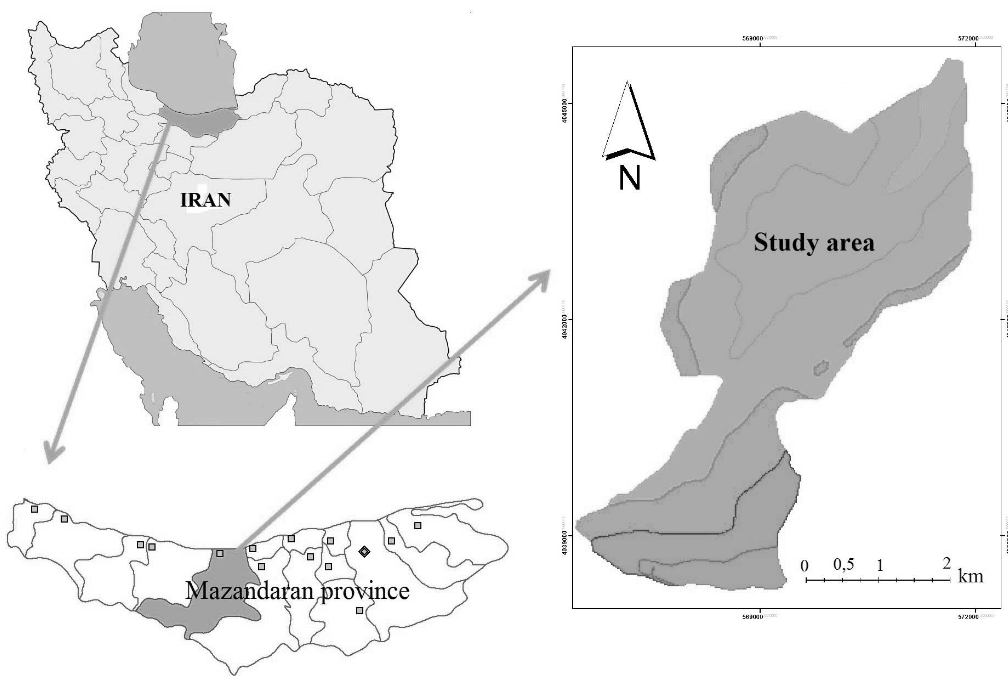

Fig. 1. Study area, Mazandaran province, Iran

graphic maps with a scale of 1:25,000 were used in ArcGIS (Version 9.3, 2015) system for mapping the digital terrain model, then the digital elevation model was classified and the slope raster layer was prepared. A hillside slope map was classified in 0–6, 6–12, 12–20, 20–30, 30–40, 40–50, 50–60, and > 60% classes, in which the proposed verified road is visible on this layer (Fig. 2).

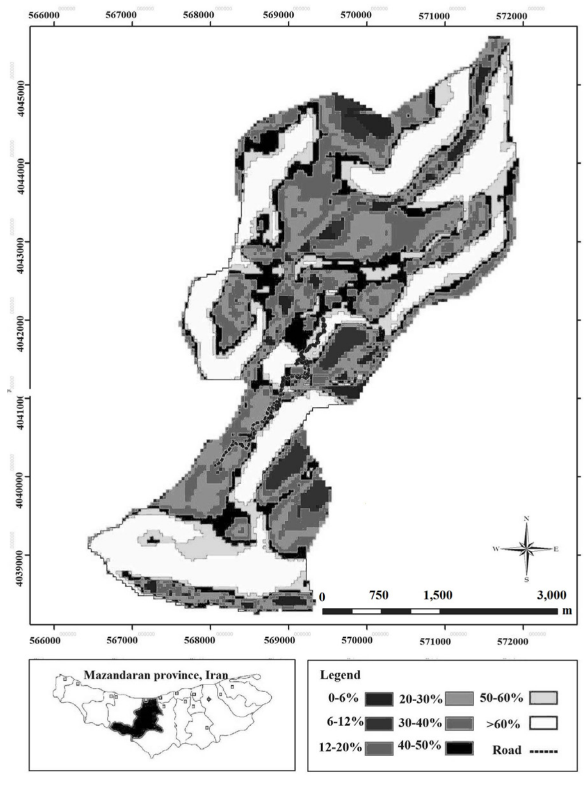

Fig. 2. Classification map of the hillside slope and the proposed road

Raster layers of the rock share were prepared from digital terrain model maps and were classified into three rock classes: soft, medium and hard classes (Ghajar et al. 2012) (Fig. 3).

Integration of layers. Prepared maps of rock share and hillside slope were integrated as a raster layer with a new layer containing 24 classes (Fig. 4). Then the layer of the proposed road with 10 km length was overlaid on the integrated layer containing a number of 18 classes integrated from the slope and rock share. Given the changes in classes of the integrated layer along the road, a number of 88 points were selected. Then the percent of hillside slope and rock share was extracted for each point.

Artificial neural network: given that the parameters of terrain hillside slope and rock share are the most important factors affecting the road cross section of forest roads, at this step by having information about these parameters, the road cross section (Fig. 5) at each point was predicted using Multilayer Perceptron Neural Network within MATLAB software (Version 7.6, 2014) (Peyrov et al. 2014). In this modelling, factors of hillside slope and rock share were considered as input parameters and road cross section was considered as output parameter of the model. In the next step, the area of road earthwork as well as the area of roadside with a 10 m width was calculated in ArcGIS system according to the predicted widths.

Collecting samples. Sampling was performed using a randomized systematic sampling method. The area of sampling plots was set at 1,000 m^2. In each plot, some characteristics including species

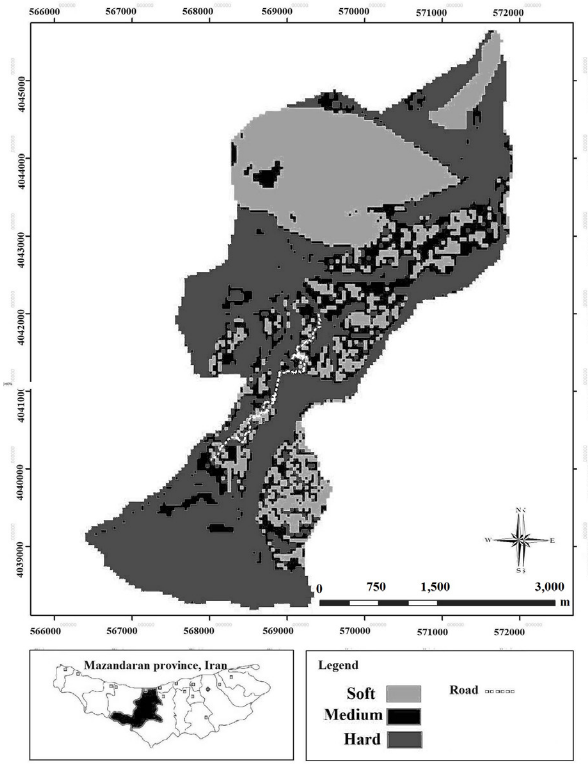

Fig. 3. Classification map of the rock share and the proposed road

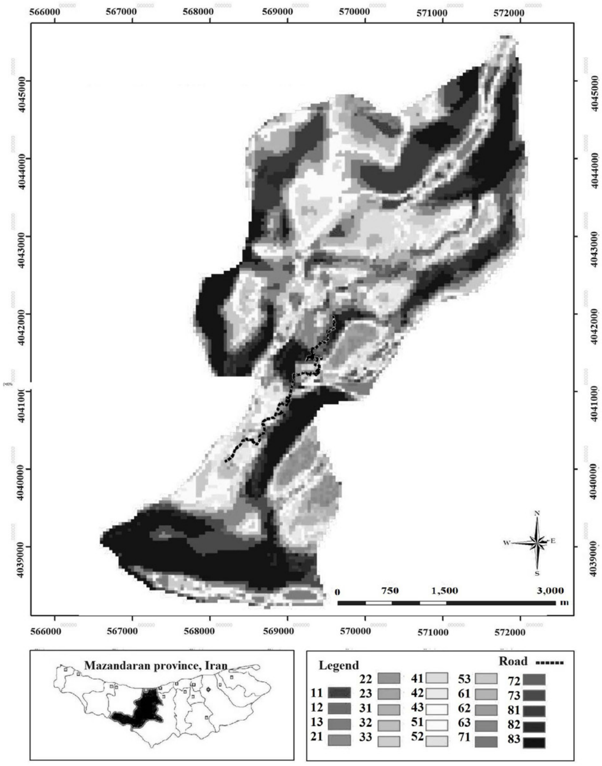

Fig. 4. Classification map of rock share and hillside slope integrated

type, DBH, tree height and density for all trees were measured. Then using a two-factor volume table of the studied forest, tree volume and annual growth volume in the plots were obtained. Finally, by putting the inventory network layer and by knowing the annual growth (m^3) for each plot the growth loss of the area of road earthwork was calculated and one-third of annual growth increment was considered to calculate the growth loss of the roadside.

RESULTS

Maps of the two parameters of hillside slope and rock share were separately integrated with the road map suggesting the amount of road that occurs in different classes of slope and rock share (Fig. 2, Table 1). The results show that the maximum length of the road had crossed from the slope classes 30–40, 40–50, and > 60%, as well as the maximum length of the road had crossed from the medium rock class.

Integration of road maps with maps of hillside slope and rock share

At this step, by integrating the maps of road, hillside slope and rock share, information for each profile was obtained. The amount of road occurring in different integrated classes obtained from the two parameters of hillside slope and rock share was calculated (Table 2).

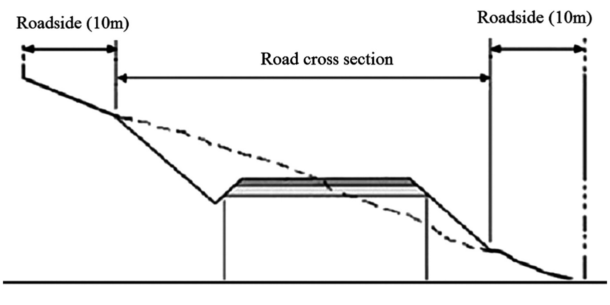

Fig. 5. Typical road section

Predicting the earthwork width

According to Table 2, by combining the two input parameters of hillside slope and rock share, earthwork width in 18 different integrated classes containing the road network was predicted using Multilayer Perceptron Neural Network.

According to the results, the slope classes of 40–50 and 50–60% had the highest earthwork

Table 1. The amount of roads that occurs in different classes of hillside slope and rock share

Hillside slope			Rock share		
(%)	roads			roads	
	(m)	(%)		(m)	(%)
12–20	278.5	2.76	soft	2,081.3	20.68
20–30	831.2	8.26	medium	4,884.1	48.52
30–40	2,395.5	23.80	hard (rocky)	3,099.9	30.8
40–50	2,443.7	24.28	–		
50–60	1,801.0	17.90	–		
> 60	2,315.4	23.00	–		
Total	10,065.3	100.00	–	10,065.3	100

width, also soft and medium classes of rock share had the highest earthwork width.

Determining the areas of earthwork operations and the roadside

Given the width of earthwork, buffer zone of earthwork operations and by considering the width of the roadside as 10 m for each side, the roadside buffer zone was calculated in GIS (Table 3).

Determining the annual growth loss due to road construction

The layer of plot centres was integrated with the layer of the buffer zone of earthwork and roadside and taking into account the annual growth in hectares, the growth loss in the earthwork area was calculated and in the roadside area the growth loss was considered as one-third of forest normal annual growth (Table 3). According to the results, the slope classes of 40–50 and 50–60% had the highest earthwork width, also soft and medium classes of rock share had the highest earthwork width. In parts with higher annual growth, a higher growth volume is lost.

DISCUSSION AND CONCLUSIONS

Information on the parameters of hillside slope and rock share was prepared in the study area in order to achieve the objectives of the study. The extracted information indicated that the maximum

Table 2. Predicted earthwork width and road length in different classes of combined layers of hillside slope and rock share

Row	Hillside slope (%)	Rock share	Integrated class code (hillside slope and rock share)	Earthwork width predicted in each integrated code	Roads in each integrated code	
					(m)	(%)
1	12–20	soft	11	12.4	79.65	0.8
2	12–20	medium	12	10.4	103.11	1.02
3	12–20	hard	13	9.4	95.80	0.95
4	20–30	soft	21	14.3	291.40	2.89
5	20–30	medium	22	12.5	209.80	2.08
6	20–30	hard	23	11.0	330.10	3.28
7	30–40	soft	31	14.6	683.00	6.79
8	30–40	medium	32	13.8	1,093.70	10.87
9	30–40	hard	33	13.1	618.80	6.15
10	40–50	soft	41	15.5	314.69	3.13
11	40–50	medium	42	13.6	1,124.90	11.18
12	40–50	hard	43	13.4	1,003.80	9.97
13	50–60	soft	51	16.3	539.50	5.36
14	50–60	medium	52	14.3	900.00	8.94
15	50–60	hard	53	13.0	361.73	3.59
16	> 60	soft	61	16.3	172.75	1.72
17	> 60	medium	62	15.9	1,452.90	14.43
18	> 60	hard	63	11.0	689.70	6.85
Total	–		–	–	10,065.3	100.00

Table 3. Growth loss in the earthwork and roadside areas

Row	Number of samples	Annual growth	Earthwork area	Roadside area	Growth loss (m^3)	
			(ha)		in earthwork area	in roadside area
1	1	0.30	0.03	0.05	0.01	0.006
2	1	0.30	0.04	0.08	0.013	0.008
3	1	0.30	0.04	0.08	0.011	0.008
4	2	7.00	0.17	0.23	1.173	0.546
5	2	1.00	0.10	0.16	0.334	0.178
6	3	2.33	0.15	0.27	0.384	0.233
7	6	1.02	0.37	0.51	1.563	0.714
8	9	2.40	0.59	0.84	1.466	0.706
9	8	5.10	0.27	0.41	1.378	0.710
10	3	6.00	0.18	0.18	1.087	0.363
11	12	4.17	0.55	0.08	1.875	0.905
12	10	4.40	0.49	0.74	2.471	1.228
13	4	4.50	0.33	0.55	1.373	0.730
14	9	4.16	0.47	0.50	2.132	0.804
15	4	4.32	0.16	0.26	0.624	0.326
16	2	4.00	0.09	0.11	0.377	0.153
17	6	4.20	1.02	1.28	4.463	1.866
18	5	5.10	0.32	0.58	1.486	0.900
Total	88	–	5.36	7.62	22.221	10.384

amount of road occurred in the hillside slope classes of 30–40, 40–50, and > 60% and the medium class of rock share (Table 1). Designing the road in areas with slopes higher than 50% can significantly increase the volume of earthwork, thereby increase economic and environmental costs (Imani et al. 2012). Peyrov et al. (2016) have reported that among the effective parameters in relation to the road cross section the slope angle is the most important. The reason for the road to occur in areas with high slope classes lies in the specific topographic conditions of the study area that is often characterized by hillside slope classes higher than 30% (Fig. 2). In the case of the parameter rock share it can be noted that the study area is often characterized by the medium and hard classes of rock share and given the fact that the road occurs in a rocky class makes the construction operations more difficult with increased economic cost, therefore, when designing the road it should occur in the medium class. Certainly, other environmental factors such as considering the low and unstable hillside have also contributed to the designing of the road. Peyrov et al. (2016) stated that the amount of rock base in soil is considered as a decisive factor for determining the road cross section and road construction project, so that by decreasing the rock base the road cross section increases while by increasing the rock base the operation of cutting the trenches is more difficult, which in turn decreases the road cross section.

The earthwork width obtained by the method of artificial neural network in 18 integrated classes of hillside slopes and rock share showed that the largest earthwork width (16.3 m) was found for profiles with soft soil and slope of 50–60% as well as for profiles with soft soils and slopes greater than 60%. With increasing the slope, the length of the cutslope trench increases and consequently the length of the cross trench as well as road cross section increase, particularly in the classes with soft soil that are lacking the rock which prevents an increase in the road cross section (Gorton 1985; Sedlak 1985; Hay 1996; Potočnik 2003). The lowest road cross section (9.4 m) was found in rocky profiles with slope of 12–20% (Table 2).

As mentioned above, by constructing a 10 km long road in the area, 5.36 ha of forest area occurs under earthwork operations and 7.62 ha of forest area is affected by the road construction as roadside area. The growth loss due to the road earthwork accounts for 22.221 $m^3 \cdot yr^{-1}$ that would be completely out of the forest growth cycle, while the growth loss in the roadside area is estimated to be 10.384 m^3. There is no doubt that appropriate roads should be constructed for the development of different parts of the country, but the important point is that the road construction in a forest should be performed by taking into account technical issues and according to correct criteria and indicators as well as considering the environment conservation, conserving forests, rangelands, water and soil resources (Nekooimehr 2006), so modelling helps managers and planners to better understand the current conditions and improve the conditions predicted for the future (Lotfalian, Parsakhoo 2012). Since in this study a qualitative criterion of growth conditions of road areas is also considered in addition to the physiographic quantitative criteria, the results can be used to evaluate the forest road network variants in terms of economic and environmental costs. It is noteworthy that the results of these researches are directly correlated with the accuracy of spatial data in the studied regions. Thus, the provision of information and thematic maps with high accuracy is necessary for forests of northern Iran in order to achieve the desired results by applying these maps as well as new methods of designing and evaluation, which could be considered as a basis for the protection, restoration and development of forests (Majnounian et al. 2007).

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