DOI: 10.20472/IAC.2015.019.130

STERGIOS TAMPEKIS
Department of Planning and Regional Development, University of Thessaly, Greece

FANI SAMARA
Department of Planning and Regional Development, University of Thessaly, Greece

STAVROS SAKELLARIOU
Department of Planning and Regional Development, University of Thessaly, Greece

ATHANASSIOS SFOUGARIS
Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Greece

OLGA CHRISTOPOULOU
Department of Planning and Regional Development, University of Thessaly, Greece

MAPPING THE ENVIRONMENTAL IMPACTS INTENSITY THAT IS CAUSED FROM THE FOREST ROADS NETWORK PLANNING BASED ON SPATIAL MULTI CRITERIA EVALUATION (MCE)

Abstract:

Sustainable management of forest resources can only be achieved through a well-organized road network compatible with the natural environment. This paper describes a method for forest road network planning and the environmental impact assessment based on Spatial Multi-Criteria Evaluation (SMCE) at the Island of Thassos, Greece. Data analysis and its presentation are achieved through a spatial decision support system using multi-criteria evaluation (MCE) with the contribution of Geographic Information Systems (GIS). In this paper we present the assessment of: the forest's opening up percentage, the forest road density, the applied skidding means (with either the use of tractors or the cable logging systems in wood skidding), the timber skidding direction, the traffic load and truck type, the distance between forest roads and streams, the distance between forest roads and the forest boundaries and if the forest roads come through unstable soils. With the assessment of the above factors we can evaluate the intensity of forest roads' environmental impacts. The Multi-Criteria Evaluation which is recommended and described at this study provides a powerful and easy to use implement in order to combine cartographic models and other image data and to define solutions to unstructured, as well as semi-structured, problems. It can also be used in order to minimize and evaluate the environmental impacts of forest roads planning.

Keywords:

forest road network planning, environmental impact assessment, spatial multi-criteria evaluation, GIS

JEL Classification: Q01, Q23, Q56

Introduction

A well-organized road network is crucial for the sustainable management of forest resources (wood production, ecotourism, water supply, or soil conservation) (Abdi *et al.*, 2009; Demir, 2007; Gaodi *et al.,* 2010; Lugoa and Gucinski, 2000). Furthermore, forest roads are recognized as a main source of sediment yield and pollution of off-site water (Fu *et al.,* 2010; Jordán-López *et al.,* 2009; Ramos-Scharro'n and MacDonald, 2007) and also ecological fragmentation and disturbance in forest landscapes (Delgado *et al.,* 2007). Forest roads cause changes in the landscapes and losses in habitat and biodiversity (Forman and Alexander; 1998, Hui *et al.,* 2003). Therefore, a new method for the forest roads planning assessment that includes financial, ecological and social parameters has to be developed (Dutton *et al.,* 2005; Heinimann, 1996). Some researchers analyzed the road network planning based on the environmental factors as well as with the use of multi-criteria-based road design, such as timber volume, slope, ground condition, distance from existing forest roads, soil type, geology, hydrographic, aspect, elevation, and tree type (Çalışkan, 2013; Eker *et. al.,* 2010; Gumus *et. al.,* 2008; Hosseini and Solaymani, 2006; Jusoff, 2008). An expert-based approach to the forest road network planning can be achieved by combining the Delphi method and the spatial multi-criteria evaluation. This methodology is useful in forest road planning because it takes under consideration environmental and cost parameters (Hayati *et al.,* 2013). Additionally, the "Evaluation of Forest Road Network Planning According to Environmental Criteria" (Firosan *et al.,* 2010), and the "Impacts, management and functional planning criterion of forest road network system in Turkey" (Demir, 2007) are also significant methods in forest roads network planning and environmental impacts' assessment.

In the Multi-Criteria Evaluation (MCE) technique, an attempt is made in order to combine a set of criteria to achieve a decision according to a specific objective (Eastman *et al.,* 1995). In the last fifteen years, much work has been directed toward integrating Geographic Information Systems (GIS) and multiple criteria evaluation (MCE) methods in the context of spatial decision support systems for planning, retail and services locations, land-based project selection, and environmental management (Eastman *et al.,* 1993; Jankowski,1995; Joerin *et al.,* 2001; Malczewski, 1999; Marinoni, 2005). The advantage of MCE is that provides a flexible way of dealing with qualitative multidimensional environmental effects of decisions (Munda *et al.,* 1995).

With the term "compatibility with the natural environment" we mean the definition, the description and the evaluation of the impacts of forest roads to the natural environment (Tampekis 2009). That requires the use of the Spatial Multi-Criteria Evaluation (SMCE) method for the assessment: i) of intensity of human impact to the forest ecosystem and ii) the forest ecosystem absorption of the forest roads.

In this paper, we focus on the intensity criteria evaluation and more specifically on the forest road density, the road spacing and the forest opening-up percentage evaluation. For the SMCE method, the assessment of the above criteria is crucial for the optimal forest road network spatial planning. The rest of the intensity and absorption criteria evaluation of our research are still in progress and they will be published in a following paper.

Materials and Methods

As study area, we chose the Greek Island of Thassos. Specifically, the study area is located at 40.5495 and 40.8351 Northern Latitude and between 24.4808 until 24.797 Western Longitude. The study area is about 38682.86 ha. For the needs of the research we used: The QGIS software, digital orthophotomaps of the area and the respective

Digital Elevation Models, DEM. We also used the forest management plan for the Island of Thassos for the years 2011-2020. The forest of the Thassos Island is non-productive due to the forest fires.

The MCE technique includes the evaluation of the intensity criteria in order to achieve the spatial variability for the optimal forest road network.

The MCE technique which is described is a recommended method that includes the evaluation of the intensity criteria (the forest's protection percentage, the forest road density, the applied skidding means, skidding direction, visitor' number and truck load, forest roads' location) and absorption criteria (forestry, topographical and society criteria) in order to achieve the spatial layout for the optimal forest road network. The evaluation criteria of intensity refer to the environmental impacts that are caused by the forest roads to the forest ecosystem. The evaluation criteria of forest ecosystem absorption refer to the ability of the environment to absorb the impacts that are caused by forest roads. This method refers to non-productive forests and we take under consideration the national forestry characteristics.

For the forest protection percentage evaluation we took under consideration that the forest roads can be used by the firefighting vehicles for the forest protection due to their direct access to the wildfires. The firefighting vehicles of the Greek Fire Service uses, are small pickup trucks (4x4) equipped with water tanks, piping and pumps that have the ability to eject water with pressure at 300 m uphill and 500 m downhill from forest roads. Thus, the forest opening-up percentage can be used as the forest protection percentage as well, due to fact that the firefighting vehicles can be utilized for the wildfires' prevention and suppression. The values that are used in this method that we recommend are based on the Greek national forest characteristics.

We agreed on the optimal ecosystem forest protection status to be the 100%. For the assessment of the intensity of the environmental impacts we used the criteria below (Dukas, 2004; Yianoulas, 2001). Each criterion is rated with a Weighting factor (based on experts' agreements) that represents the intensity value.

Intensity criteria in non-productive forests.

The intensity criteria that were used are:

I. ***Road Density and Forest Protection Percentage****.* The percentage of the excess or the reduction of the values D=12.5-15 m/ha, forest roads' spacing S=667-800 m and the forest protection percentage which is < 85%, is rated totally as the reduction of the optimum 100. Weighting factor: 3

II. ***Applied Skidding Means.*** The percentage of the trees' skidding that are not extracted with the use of cable logging systems or with draught animals or with the combination of them, is rated as the reduction of the optimum 100. Weighting factor: 2

III. ***Skidding direction (draught animals, cable logging systems).*** The skidding direction percentage which isn't achieved in diagonal or in parallel layout, comparing to the theoretical skidding distance, is rated as the reduction of the optimum 100. Weighting factor: 1

IV. ***Visitors' number and truck load.***

- The excess percentage of the visitors' number, in comparison to the reception capacity of the space (based on the fact that the number of Thassos habitats can visit the forest without causing impacts), is rated as the reduction of the optimum 100. Weighting factor: 2.
- The excess percentage of trucks loading due to truck overloading which is larger than the permitted by the national regulations is rated as the reduction of the optimum 100. Weighting factor: 2

V. *Forest Roads' Location.*

• The forest roads' distance from the main streams should be enough not to affect the forest ecosystem. The percentage of forest roads that pass through the valley and the distance from the margins of the stream is less than 10 m, is rated as the percentage reduction of optimum the 100 as given in the table below:

Table 1. Intensity evaluation rating due to the forest roads' distance from the streams.

Distance from streams (m)	Rate (%)
>10	100
5-10	50-100
0-5	0-50

Weighting factor: 3

• The percentage of the roads that pass through in less than 10 meters outside the forests' boundaries or 20 meters within the forests' boundaries is rated as the percentage reduction of the optimum 100. Weighting factor: 3

• Forest roads shall not be going through unstable soils where they may be slipping, sliding or have failures in the construction of embankments. The layout design rate of forest road, passing through a clay soil, large exposures streams, unstable soils, is rated as a percentage reduction of the optimum 100. Weighting factor: 3

The weighted average of the environmental impact intensity evaluation (ΣI), is equal to the sum of the products $\Sigma(I \times W_I)$ divided by the sum of the weighting factors (ΣW_I).

$$\Sigma I = \Sigma(I \times W_I) / \Sigma W_I \qquad (1)$$

Where:

I= the criterion value assessment (%) that evaluates the impact intensity which is not negative,

W_I= the weighting factor of each intensity criterion

ΣW_I= the sum of the Weighting values of each intensity criterion

Results and Discussion

The rates of the Intensity criteria

The rates of each intensity criterion of impacts that are caused from forest roads' construction to the natural environment are:

***Road Density and Forest Opening up percentage**.* The assessments of i) the forest road density for the island of Thassos is D_{ex}=L/F= 36.5955 m/ha, where L= main forests roads' length (m) and F=forests' area (ha), (Fig. 1 and 2), and ii) the percentage of forest protection is E=70.39% (Fig. 3 and 4). With the QGIS software we create buffers (300 m uphill and 500 m downhill from forest roads) and as a result we have the forest protection map (Fig. 3) and the geodatabase.

Figure 1. Map of roads' network in Thassos Island.

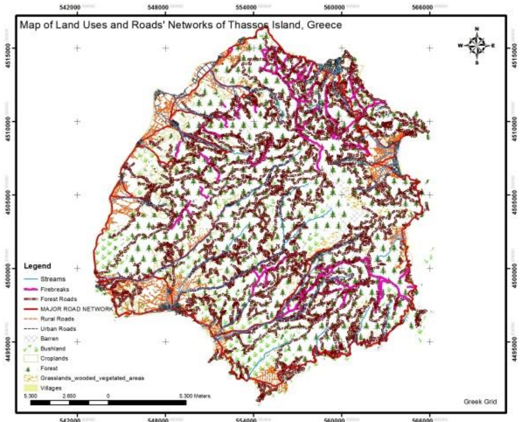


Figure 2. Graph of the roads' length (m) in Thassos Island.

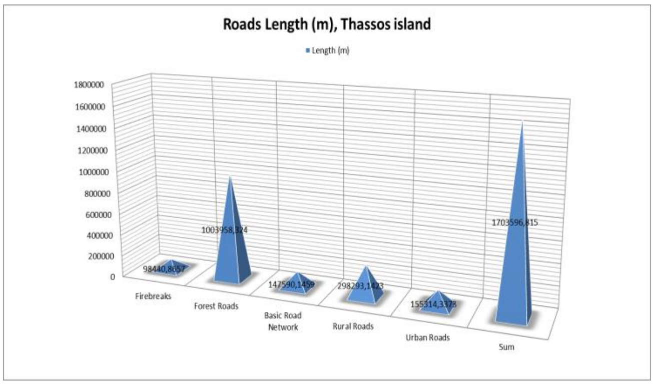


Figure 3. Percentage of forest protection in Thassos Island.

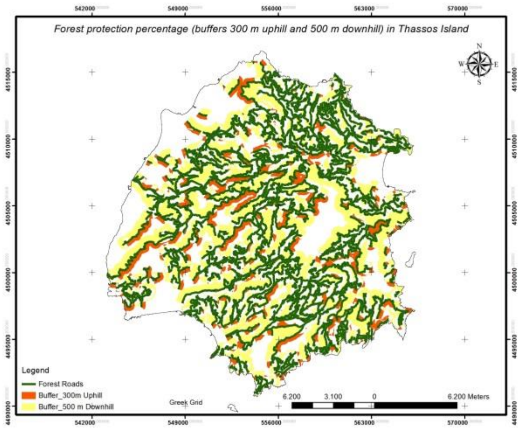
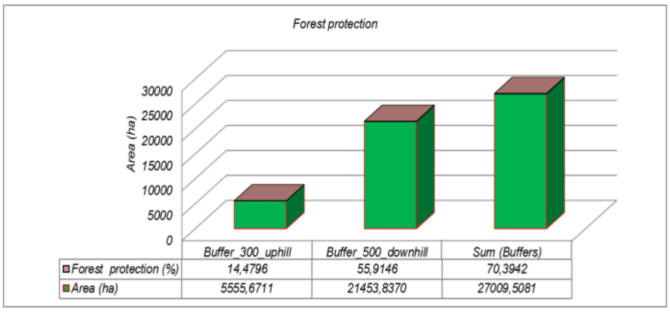


Figure 4. Forest protection percentage.



So, the excess from the road density values (D=12.5 - 15m/ha), is 36.5955-12.5=24.0955m/ha and 36.5955-15=21.5955m/ha.
The excess percentage is 100*24.0955/36.5955=65.84% and 100*21.5955/36.5955=59.01%.
Their average is (65.84+59.01)/2=62.425%.
The reduction percentage from the forest protection percentage which is smaller than 85%, is 85-70.39=14.61%.
Finally, the sum is 62.425+14.61=77.035%. This percentage is totally rated as the reduction percentage from the optimum 100.
Concluding, the value of the criterion is evaluated 100-77.035=22.965%. Weighting factor: 3
Applied Skidding Means. The forests in the study area have not been productive during the last 25 years and do not produce timber for any use because of the fires that had broken out in the decade of 1980. Thus, the skidding means are not used for timber skidding. This criterion is therefore not rated. Weighting factor: -
Skidding direction (draught animals, cable logging systems). This criterion is not rated because of the fact that in the study area wood skidding has not been carried out due to the forest protection and the unproductive management. Weighting factor: -
Visitor' number and Truck load.
• In the study area, there isn't any excess of the visitors' number, in comparison to the reception capacity (based on the fact that the number of Thassos habitats can visit the

forest without causing impacts) of the space. So, the excess percentage is 0%. The value of the criterion is evaluated as 100-0=100%. Weighting factor: 2.

- In the study area, there is not any truck presence larger than the permitted by the national regulations, due to the fact that the forest in the area has not been productive during the last 25 years. Thus, the percentage of the vehicles is 0%. The value of the criterion is evaluated as 100-0=100%. Weighting factor: 2

Forest Roads' Location.

- The distance of the forest roads from the streams should be enough not to affect the forest ecosystem. For the evaluation of this criterion, QGIS has been used. Finally, the percentage of forest roads (Fig. 5) that pass through the valley and the distance from the margins of the stream is less than 10 m, is given in the table below:

Table 2. Intensity evaluation rating due to the forest roads' distance from the streams.

Distance from streams (m)	Rate (%)	Forest roads' length (m)	Final Rate (%)	Road percentage (%)	Criterion rate
>10	100	959185.3245	100	95.5409	95.5409
5-10	50-100	17887.2017	75	1.7817	1.3363
0-5	0-50	26879.8724	25	2.6774	0.6694
Total		1003952.3985			**97.5465**

The criterion rate for the distance from the forest's boundaries is 97.5465. Weighting factor: 3

- The percentage of the roads that are passing through in less than 10 meters outside the boundaries of forests or 20 meters within the boundaries of forests (Fig. 6), is evaluated with the use of QGIS. Finally, the percentage of these roads is given in the table below:

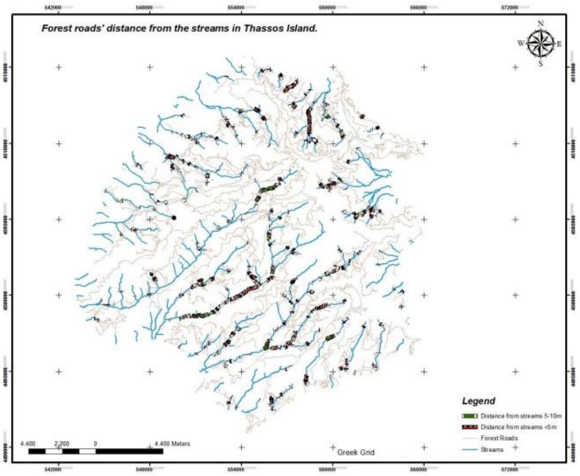
Table 3. The forest roads' distance criterion evaluation from the forest's boundaries (less than 10 m outside and 20 m inside).

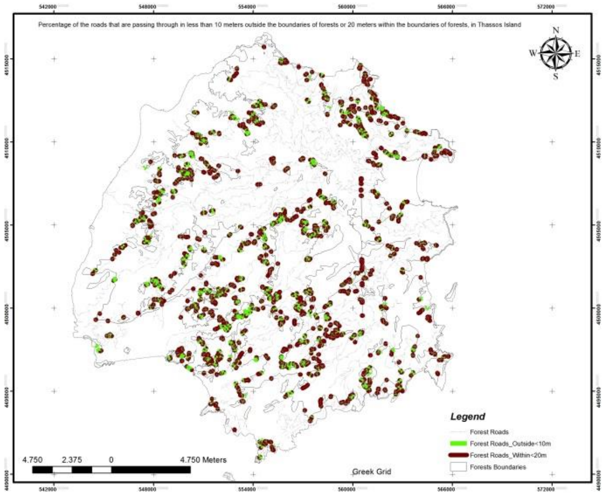
Forest road distances from the forest boundaries	Forest roads' length (m)	Road percentag e (%)	Criterion evaluation (Difference from optimum 100)	Criterion rate (Average)
Forest roads inside boundaries in distance <20 m	50797.8055	5.0598	94.9402	
Forest roads outside boundaries in distance <10 m	29213.7161	2.9099	97.0901	
Rest of Forest roads	923940.8770	-	-	
Total	1003952.398 5			**96.0152**

The criterion rate for the distance from the forest's boundaries is 96.0152. Weighting factor: 3

Figure 5. Forest roads' distance from the streams in Thassos Island.

Figure 6. Percentage of the roads that are passing through in less than 10 meters outside the boundaries of forests or 20 meters within the boundaries of forests in Thassos Island.





- The fieldwork results showed that the forest roads of Thassos island, don't pass through clay soils, large exposures streams and unstable soils. So, the layout design rate of forest roads that pass through hazardous sites is rated 0%. Thus, the criterion rate is 100-0=100%. Weighting factor: 3

In the table below, the average of the multi-criteria intensity evaluation due the forest roads' construction at the island of Thassos, is presented.

Table 4. Multi-criteria evaluation of intensity due the forest roads' construction.

Intensity			
Criteria	**Rate**	**Weighting factor**	**Total**
Road Density and Forest protection percentage	22.965	3	68.90
Applied Skidding Means	-	-	-
Skidding direction	-	-	-
Traffic load and truck type			
Excess percentage of the visitors' number	100.000	2	200.00
Excess percentage due to overloaded vehicle wheels	100.000	2	200.00
Forest road location			
Forest road distance from the streams	97.5465	3	292.64
Forest road distance from the forest boundaries	96.015	3	288.05
Forest roads that pass through hazardous sites	100.000	3	300.00
Total		16	1349.58
Average $\Sigma I = \Sigma(I \times W_I) / \Sigma W_I$		**134958/16=84.35%**	

Conclusions

By applying this method, the average of the environmental impact intensity evaluation due the forest roads' construction at the island of Thassos, is ΣI =84.35%.
The development and the application of the mapping of the environmental impacts evaluation that are caused to the natural environment based on the MCE technique, with the use of the intensity criteria evaluation is an innovative tool. Consequently, with this method we will ensure the best protection and at the same time the sustainable utilization of the forest resources.
Additionally, it will be valued if there are any impacts to the natural environment and if some of the forest roads had been constructed legally or not according to the guidelines.

This method plays a crucial role in the optimum solution selection (spatial, financial, forest, topographical, social and environmental) for the forest roads' planning. It can also be customized to each areas' particularities and to be applied for the creation of a new integrated decision support system (DSS).

Acknowledgements: This research has been co-financed by the European Union (European Social Fund-ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Thales. Investing in knowledge society through the European Social Fund.

References

ABDI, E., MAJNOUNIAN, B., DARVISHSEFAT, A., MASHAYEKHI, Z., & SESSION, J. (2009). A GIS-MCE based model for forest road planning. Journal of Forest Science, 55(4), 171–176.

AKAY, A. E., WING, M. G., SIVRIKAYA, F. AND SAKAR, D. (2012). A GIS-based Decision Support System for Determining the Shortest and Safest Route to Forest Fires: A Case Study in Mediterranean Region of Turkey. Environ. Monit. Assess., 184(3): 1391-1407.

ÇALIŞKAN, E., (2013). Planning of Forest Road Network and Analysis in Mountainous Area. Life Sci. J., 10(2), 2456-2465.

DELGADO, J. D., AREVALO, J. R. AND FERNANDEZ-PALACIOS, J. M., (2007). Road Edge Effect on the Abundance of the Lizard Gallotia galloti (Sauria: Lacertidae) in Two Canary Islands Forests. Biodivers. Conserv [16], 2949–2963.

DEMIR, M., (2007). Impacts, management and functional planning criterion of forest road network system in Turkey. Transportation Research Part A [41], 56–68.

DUKAS, K., (2004). Forest Works and Natural Environment. Publications Giahoudi, Thessaloniki, Greece. 227-310pp.

DUTTON, A. L., LOAGUE, K. AND WEMPLE, B. C., (2005). Road Sediment Production and Delivery: Processes and Management. Earth. Surf. Proc. Land [30], 325-338.

EASTMAN J. R., KYEM P. A. K., TOLEDANO J. AND JIN W., (1993). GIS and Decision Making. Vol. 4, Explorations in Geographic Information System Technology, Geneva, UNITAR.

EASTMAN J.R., JIN W., KYEM P.A.K., TOLEDANO J., (1995). Raster Procedures for Multi-Criteria / Multi-Objective Decisions. Photogrammetric Engineering & Remote Sensing 61 (5), 539-547.

EKER, M.,& COBAN, H.O., (2010). Impact of road network on the structure of a multifunctional forest landscape unit in southern Turkey, Journal of Environmental Biology [31], 157-168.

FIROZAN, A. H., HASHEMI, S. A., & CHAI, M. M. F., (2010). Evaluation of Forest Road Network Planning According to Environmental Criteria. American-Eurasian J. Agric. & Environ. Sci. 9 (1), 91-97.

FORMAN, R. T. T. AND ALEXANDER, L. E., (1998). Roads and Their Major Ecological Effects. Annu. Rev. Ecol. Syst. [29], 207–231.

FU, B., NEWHAM, L. T. H. AND RAMOS-SCHARRON, C. E., (2010). A Review of Surface Erosion and Sediment Delivery Models for Unsealed Roads. Environ. Modell. Softw. [25], 1–14.

GAODI, X., WENHUA, L., YU, X., BIAO, Z., CHUNXIA, L., KAI, A., JIXING, W., KANG, X., & JINZENG, W., (2010). Forest ecosystem services and their values in Beijing. Chinese Geographical Science 20(1), 51–58.

GREENE, R., DEVILLERS, R., LUTHER, J.E., AND EDDY, B. E., (2011). GIS-Based Multiple-Criteria Decision Analysis, Geography Compass 5/6 (2011), 412–432.

GUMUS, S., ACAR, H. H. AND TOKSOY, D., (2008). Functional Forest Road Network Planning by Consideration of Environmental Impact Assessment for Wood Harvesting. Environ. Monit. Assess. [142], 109–116.

HAYATI E, MAJNOUNIAN B., ABDI E., SESSIONS J., MAKHDOUM M., (2013). An expert-based approach to forest road network planning by combining Delphi and spatial multi-criteria evaluation. Environmental Monitoring and Assessment, 185 (2), Springer Publications, 1767-1776.

HEINIMANN, H. R., (1996). Opening-up Planning Taking into Account Environmental and Social Integrity. Proceedings of the Seminar on Environmentally Sound Forest Roads and Wood Transport, Romania, 62–69.

HOSSEINI, S. A., & SOLAYMANI, K., (2006). Investigation of effective factors for path tracing using GIS in Kheyroud forest (Iran-Mazadaran province). Pakistan Journal of Biological Sciences, 9(11), 2055–2061.

HUI, C., SHUANG-CHENG, L., & YI-LI, Z., (2003). Impact of road construction on vegetation alongside Qinghal-Xizang highway and railway. Chinese Geographical Science, 13(4), 340–346.

JANKOWSKI P., (1995). Integrating geographical information systems and multiple criteria decision making methods. International Journal of Geographical Information Systems [9], 251–73.

JANKOWSKI, P., LIGMANN-ZIELINSKA, A., SWOBODZINSKI, M., (2008). Choice Modeler: A Web-based Spatial Multiple Criteria Evaluation Tool. Transaction in GIS 12(4): 541-561.

JOERIN F., THERIAULT M., AND MUSY A., (2001). Using GIS and outranking multi-criteria analysis for land-use suitability assessment. International Journal of Geographical Information Science [15], 153–74.

JORDÁN-LÓPEZ, A., MARTÍNEZ-ZAVALA, L., & BELLINFANTE, N., (2009). Impact of different parts of unpaved forest roads on runoff and sediment yield in a Mediterranean area. Science of the Total Environment [407], 937–944.

JUSOFF, K., (2008). Construction of new forest roads in Malaysia using a GIS-based decision support system. Computer and Information Science, 1(3), 48–59.

LUGOA, A. AND GUCINSKI, E., (2000). Function, Effects, and Management of Forest Roads. For. Ecol. Manag. [133], 249–262.

MALCZEWSKI J., (1999). GIS and Multicriteria Decision Analysis. New York, John Wiley and Sons

MARINONI O., (2005). A stochastic spatial decision support system based on PROMETHEE. International Journal of Geographical Information Science [19], 51–68.

MUNDA, G., NIJKAMP, P., RIETVELD, P., (1995). Qualitative multi-criteria methods for fuzzy evaluation. European Journal of Operational Research 82(1), 79–97.

RAMOS-SCHARRO’N, C. E., & MACDONALD, L. H., (2007). Runoff and suspended sediment yields from an unpaved road segment, St. John, US Virgin Islands. Hydrological Processes 21(1), 35–50.

TAMPEKIS, S., (2009). The compatibility of the forest opening-up works with the natural environment, for the development of the mountainous region of Metsovo,” Ph.D. dissertation, Dept. Forestry and Natural Environment, Aristotle University of Thessaloniki, Greece.

YIANOULAS, V., (2001). Forest opening-up with modern machinery. Technico-econmic, environmental effects. Ph.D. Thesis, Aristotle University of Thessaloniki.