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Research Article

Environmental Impact Assessment of Forest Roads using the Goecybernetic Assessment Matrix (GAM): A case study from the Kheyrud forest, Iran

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Abstract
Environmental Impact Assessment (EIA) has been recognized as an analysis of the impacts that a project can impose on the environment, with the purpose of balancing the positive and negative impacts of the project. Forest road construction is one of the costliest and most important projects that its outcomes need to be evaluated because of being involved in the development of different forestry operations. The purpose of the current study was to assess the environmental impacts of a road network in the Kheyrud forest (Hyrcanian forest), in northern Iran, at three stages including before, during, and after the road construction phase. We used Geocybernetic Assessment Matrix (GAM) criteria listed scores by using the views of experts who have observed the problems associated with road construction in three stages. By applying this method, a suitable tool is obtained to ensure that the project is properly implemented or should be stopped. It can be a method of determining, predicting and interpreting the environmental, social and economic impacts of road construction on the whole environment and the health of the ecosystems on which human life and sustainability depend. The results indicated that the total geocybernetic score was in the range of 0 to -121 (very weak unsustainability) for before, during and after road construction, indicating that although road construction in the Kheyrud forest had negative impacts on the environment especially during the construction phase, social and economic services, especially after road construction, have left the total geocybernetic score in that range.

Keywords: Assessment matrix, EIA, Environment–human relationship, Sustainability.

1. Introduction
Environmental Impact Assessment (EIA) is a process for assessment of the effects of a proposed development on the environment. The mitigation of negative impacts may then be considered in the design process by the avoidance, elimination or the reduction of their sources together with the enhancement of positive effects (Ryan et al., 2004). The main and primary aspect of using assessment as a planning tool is its use at all stages of project development, including planning, final design of construction operations, start of its operation and utilization (Shariat & Monavari, 1997). Forest roads provide necessary access to the forest for forest protection, timber extraction and recreation (Deljouei et al., 2018). Apart from the initial establishment, forest roads represent the greatest investment by the forest owners. There is a need to ensure that the forest road is compatible with environmental values (Ryan et al., 2004). Any design and construction of a road in the forest, for whatever purpose (e.g., wood utilization, tourism use and residential communication), should be comprehensive and

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consider the following principles: forest as an ecosystem, forest as an important factor in water storage and treatment, observation of soil mass movements, forest as a beautiful and inspiring phenomenon, forest as the most valuable biodiversity reserve, tourism, recreation and hunting, wood production and transportation, a goal in forest road design and socio-economic foundations in forest road design (Sarikhani & Majnounian, 2000). Forest roads can cause a variety of impacts on local wildlife that may lead to extirpation: facilitating the spread of invasive organisms, causing death or harm by vehicle strikes, and changing the behavior of animals to their detriment (Boston, 2016). The environmental impacts of forest road construction and operation are possible in various ways, the most recent of which is the Geocybernetic Assessment Matrix (GAM). The GAM is a novel sustainability assessment tool, first described in Phillips (2016). GAM is based upon the Rapid Impact Assessment Matrix (RIAM) (Pastakia & Jensen, 1998), which has become a respected method used in EIA (Phillips & Whiting, 2016). Unlike RIAM, where only environmental impacts are evaluated, GAM evaluates the chosen or designated parameters against assessment criteria with respect to the three dimensions of sustainability: environmental, social and economic (Phillips, 2016).

Many studies have assessed the environmental impacts of roads throughout the world, each of which has used a different approach. For example, Malakouti (2005) assessed positive and negative impacts of the Imamzadeh Hashem-Anzali freeway project using two methods of Adhoc checklist and overlay, and confirmed that the agricultural lands and gardens were identified as the most vulnerable zones to the project implementation. Jaafari et al. (2011) assessed the positive and negative consequences of forest road construction project at the Faculty of Natural Resources of Tarbiat Modares University on environment using the Pastakia matrix and reported that the forest road construction project in general had 39 negative impacts versus 13 positive impacts on different environments. Falahatkar et al. (2010) examined the environmental impacts of Qomishloo freeway on the status of Qomishloo Wildlife Refuge in Isfahan Province using two methods of ICOLD matrix and checklist and concluded that the sum of values of the projects had 182 positive points and 682 negative points and the project is rejected. Ameri Golestan (2013) by assessing the environmental impacts of Bazoft road in Khuzestan Province using the Bayesian network method concluded that 79.3% of the impacts occurred in the extreme range, indicating that the desired road construction had a great negative impact on the environment and environmental standards have not been met for the construction of this road. Dadvar khani et al. (2015) by examining the environmental impacts of the construction of the North Tehran Freeway in Kan-Solaghan district concluded that the project could be implemented by providing corrective and conditional improvements. Delnavaz & Khalesi (2016) by assessing the environmental of construction of Shahid Sadr Class Highway at Construction and Utilization stages using methods of coding and modified Leopold matrix (Iranian matrix) concluded that the project had 5 positive impacts, 30 negative impacts and 229 activities with no environmental impact at the construction stage using coding method and at the utilization stage, the project had 19 positive impacts, 5 negative impacts and 160 activities with no environmental impact. Gumus et al. (2008) used Geographic Information System (GIS) to evaluate data and planning process of forest road networks in Turkey and concluded that 90.2% of roads were planned for the forest areas where there is likely to be a minimal negative environmental impact. Igondova et al. (2016) examined the environmental impacts of roads in Slovakia, in their results proposed a scale for each criterion to evaluate the total significance of impacts. In this way, detailed significant ecological impacts can be found which will help lead to proposed correct mitigation measures and post-project analysis. Phillips (2016) assessed Part 1 of the UK Climate Change Act (2008) by using the GAM method, and concluded that this part may not reach the desired aims in contributing towards sustainable development through the noted mechanisms for carbon budgets and targets. Ritter et al. (2017) examined the environmental impacts of the latest and largest infrastructure projects in Amazonia. Handa et al. (2019) studied the environmental impacts of the highway in the Himalayan region, and tried to understand the quality of air, soil and water as well as impacts on socio-economic communities of local habitats from highway and road construction activities.

The abovementioned literature reviews demonstrated that all of EIAs fall short of suitable evaluation of the predicted impact of infrastructure development locally and that their results had barely informed decisions. According to the above-mentioned conducted national and international studies, it seems that different construction projects have different impacts on the natural resources, so new methods are needed to investigate the impacts of human activities on the natural environment. In this study, three stages are considered for the road project: 1) before road construction stage, 2) during road construction and 3) after road construction stage or road utilization stage. By obtaining the geocybernetic scores of environmental, economic, social and total, using the GAM method, one can compare geocybernetic scores before, during and after road construction and study changes from past to present.

2. Materials and methods

2.1. Study area

This study was conducted in the Kheyrud educational and research forest located in the Mazandaran Province in northern Iran (Figure 1). The site is located 7 kilometers east of the Nowshahr city between 27′ 36° to 40′ 36° north latitude and 32′ 51° to 43′ 51 ° east longitude. The total area of the area is about 8,000 ha with Kheyrud River as the main drainage. The lowest altitude is zero and the highest is 2200 m. The road length in the study area is about 55 km. Route selection and construction of the roads for Kheyrud forest management was started since 1967.

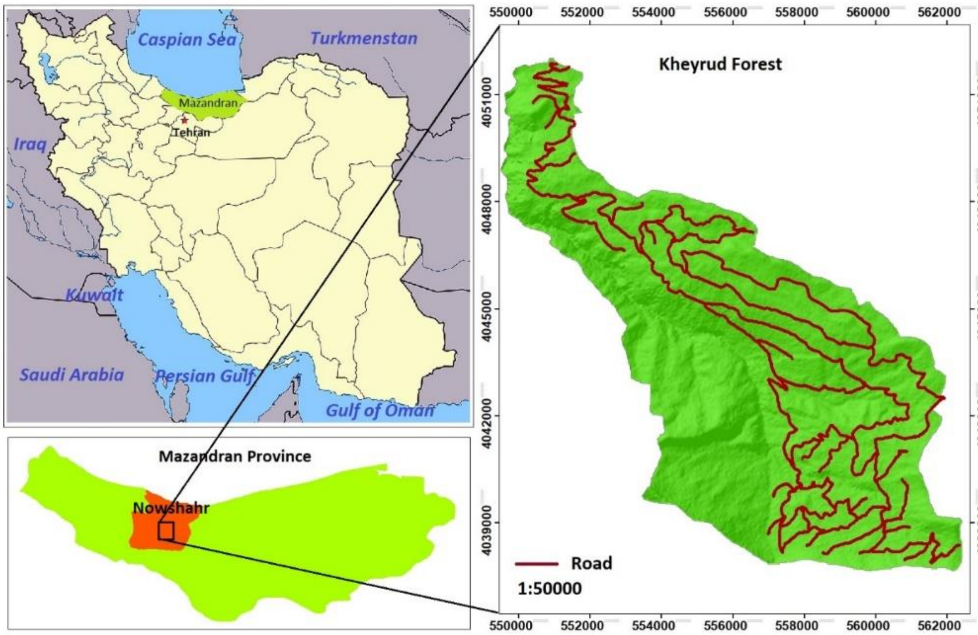

Figure 1. Location of the study area in the Mazandaran province of Iran.

Road construction projects include activities that affect environmental components. For each of the environmental components of the area, a geocybernetic score is calculated using the criteria listed in Table 1 before, during and after the project implementation.

To identify the activities' impacts scientifically, we have used the views of experts who have observed the problems associated with road construction to score the components before, during and after the project implementation. The environmental activities and components of the area are as follows:

Project activities: workshop equipping, recruitment, repair, maintenance, tree cutting, cleansing, root and trunk transport, material handling, explosion, excavation, embankment, vibration, staff traffic, machinery traffic, leveling, land preparation, spraying, noise pollution, water diversion, land use change, and pest control.

2.2. Components of the area before project implementation

A. Environmental components: air quality, noise quality, soil erosion, soil properties, drainage, land shape, landslide and drift, surface water quality, groundwater quality, springs, slope, orientation, altitude, aquatic ecosystem, terrestrial ecosystem, plant species, animal species, animal population, animal migration, animal habitat, plant habitat, plant density, endangered species, mycorrhiza, animal behavior patterns, species diversity, and animal reproductive place.

B. Social components: welfare, health, housing, population, migration, literacy, hunting, monuments, physical health, mental comfort, outing, landscape beauty, safety, security, and quality of life.

C. Economic components: transportation, land use, income level, agriculture, real state, employment, and unemployment (Falahatkar et al., 2010).

Table 1. Assessment criteria for GAM (Phillips, 2016).

Criteria	Scale	Description
A1: Significance of paradigm	3	High significance
	2	Moderate significance
	1	Minor significance
	0	Non-applicable/non existent
A2: Magnitude of paradigm conformity	3	Conforms to strong degree
	2	Conforms to moderate degree
	1	Conforms to minor/no degree
A3: Nature of impacts	+3	Major positive
	+2	Moderate positive
	+1	Minor positive
	0	No impact
	-1	Minor negative
	-2	Moderate negative
	-3	Major negative
B1: Spatial impacts	5	National to international impacts
	4	Regional to national impacts
	3	Local and outside vicinity
	2	Local only
	1	No impact/non-applicable
B2: Temporal impacts	4	Long-term (N10 years)
	3	Medium-term (6–10 years)
	2	Short-term (0–5 years)
	1	No impact/non-applicable

2.3. Components of the area during project implementation

A. Environmental components: impact of excavation on noise, impact of excavation on Erosion, impact of earthworks on drainage, impact of earthworks on topography, impact of earthworks on air pollution, impact of earthworks on noise pollution, impact of earthworks on surface water quality, impact of herbicides on surface water quality, impact of loading of materials on noise, impact of painting on surface water quality, impact of road shoulder construction on soil erosion, impact of compaction on soil erosion, river bank erosion, degradation of roadside lands, slope failure, impact of clearing on terrestrial ecosystem, herbicide impact on plant habitat, herbicide impact on animal habitat, herbicide impact on plant density, impact of explosion on animal habitat, impact of bedding and pavement on an animal habitat, bridge construction impact on aquatic ecosystem, impact on trees, and impact on wildlife.

B. Social components: noise for local communities, impact of employment on public participation, and impact of employment on population density.

C. Economic components: impact of manpower on regional income, cost of land use change, road construction cost, and impact of construction operations on Tourism (Jaafari et al., 2011).

2.4. Components of the area after project implementation

A. Environmental components: impact of machinery traffic on air, impact of machinery traffic on noise, impact of machinery traffic on microclimate, impact of machinery traffic on sedimentation, impact of machinery traffic on soil erosion, impact of machinery traffic on surface water quality, impact of waste transport on terrestrial ecosystem, impact of waste transport on aquatic ecosystem, impact of machinery traffic on terrestrial ecosystem, impact of machinery traffic on aquatic ecosystem, impact of road on landscape, and impact of machinery traffic on plant habitat.

B. Social components: impact of road on development of forestry management plans, impact of road on increasing conservation of forest, impact of road on increasing services to upstream villages, impact of road on population of the region, and impact of road on regional tourism.

C. Economic components: employment of manpower, reduced cost of timber, transit of goods to upstream villages, and tourism expansion (Jaafari et al., 2011).

After collecting the questionnaires and analyzing the data, socioeconomic geocybernetic score was calculated as follows:

The assessed criteria scores are used to produce a total parameter score for each dimension. A total score is referred to as a ‘geocybernetic score’ (GS). Therefore, there are three GS totals obtained for each parameter, which are: GS (E) — environmental geocybernetic score; GS(S) — social geocybernetic score; and GS (Ec) — economic geocybernetic score. These reflect the strengths or weaknesses of each dimension in respect to the parameter's contribution towards sustainable development. Furthermore, the GS parameter totals can indicate the direction taken for achieving sustainability through a co-evolutionary pathway in regards to each of the dimensions. Therefore, the obtained GS totals reflect whether ecospheric (environmental) or anthropospheric (social and/or economic) factors are evident and tend to dominate (Phillips, 2016).

The geocybernetic score (GS) for each assessed parameter in respect to GS (E), GS(S), and GS (Ec) is obtained using a simple set of mathematical formulae, which has been adapted and extended from the RIAM.

Criteria A groups are multiplied together to provide the weighting component of each score, whilst Criteria B groups are added together to ensure that no influence of the overall geocybernetic score can occur.

$$A1 \times A2 \times A3 = A(T) \tag{1}$$

$$B1 + B2 = B(T) \tag{2}$$

$$A(T) \times B(T) = GS(x) \tag{3}$$

Where A1, A2, and A3 are Criteria A groups, B1 and B2 are Criteria B groups, A (T) is Criteria A total (Equation 1), B (T) is Criteria B total (Equation 2), GS(x) is Geocybernetic score and where ‘x’ is E, S or Ec (Equation 3).

To determine GS (A) (Equation 4), the following simple equation is used:

$$GS(A) = \frac{GS\left(S\right) + GS\left(Ec\right)}{2} \tag{4}$$

The final stage is to determine GS (T) and the indicated nature of sustainability or unsustainability deemed to be occurring (Equation 5). GS (T) is the total geocybernetic score which comprises the environmental and anthropospheric GS totals of a parameter. Therefore, GS (T) is determined by adding together the obtained parameter values of GS (E) and GS (A):

$$GS(T) = GS\left(E\right) + GS\left(A\right) \tag{5}$$

The value range of GS (T) is $-486 \leq$ GS (T) $\leq +486$. The indicated range of sustainability or unsustainability for GS(E), GS(S), GS(Ec), GS(A) and GS(T) is obtained by using Table 2.

Table 2. The GAM range bands. a) is the range bands for GS(E), GS(S), GS(Ec) and GS(A); and b) is the range bands for GS(T).

GS score	GS range bands	Description of GS range bands
a)		
+183 to +243	+VS	Very strong sustainability
+122 to +182	+S	Strong sustainability
+61 to +121	+W	Weak sustainability
+1 to +60	+VW	Very weak sustainability
0 to -60	-VW	Very weak unsustainability
-61 to -120	-W	Weak unsustainability
-121 to -182	-S	Strong unsustainability
-183 to -243	-VS	Very strong unsustainability
b)		
+365 to +486	+VS	Very strong sustainability
+243 to +364	+S	Strong sustainability
+122 to +242	+W	Weak sustainability
+1 to +121	+VW	Very weak sustainability
0 to -121	-VW	Very weak unsustainability
-122 to -242	-W	Weak unsustainability
-243 to -364	-S	Strong unsustainability
-365 to -486	-VS	Very strong unsustainability

3. Results and discussion

Table 3 shows the evaluation of geocybernetic scores before road construction. The number of environmental, social, economic and total components was and 8, 6, 2 and 16, respectively. Based on resident experts' point of view, soil erosion achieved the lowest score of the environmental geocybernetic score of It is because of grazing livestock and hunting in the study area before road construction. Soil and biosphere are often the most important elements because the construction of forest road causes irreversible impacts on the local scale (Heinimann, 1998). Parsakhoo et al. (2014) and Sezgin Hacisalihoğlu et al. (2019) reported the impact of forest road on top soil erosion and sediment yield and some studies identified roads as the main source of sediment in forest ecosystems (Rahbari Sisakht et al., 2014). Previous research have revealed that road construction increases erosion rates by 30 to 300 times (Abdi & Majnounian, 2018).

Table 4 shows the evaluation of geocybernetic scores during road construction. Among geocybernetic scores, the highest scores were associated with the social geocybernetic score of impact of employment on public participation and economic geocybernetic score of impact of manpower on regional income. The number of environmental, social, economic and total components was 20, 3, 4, and 27, respectively. Wilkie et al. (2000), Demir (2007) and Rezaei Motlagh et al. (2018) also reported the road constructing positive effect on social improvement which are consistent with the results GAM. Also, the existence of road networks makes logging practices more efficient (Abdi & Majnounian, 2018). The lowest scores was belong to the environmental geocybernetic score of impact of earthworks on natural drainage patterns, impact of earthworks on surface water quality and impact of herbicides on surface water quality. This is consistent with the literature that introduced roads as a strong disturbance factor in the forest environment (Forman et al., 2003). Due to road construction works performed by road construction machines and blasting operations, the points related to these variables are clearly effective in the environmental geocybernetic score.

Table 3. Evaluation of geocybernetic scores before road construction.

Component	**Geocybernetic scores**																	
	Environment						**Social**						**Economic**					
	GS (E)	**A1**	**A2**	**A3**	**B1**	**B2**	**GS (S)**	**A1**	**A2**	**A3**	**B1**	**B2**	**GS (Ec)**	**A1**	**A2**	**A3**	**B1**	**B2**
Soil erosion	-48	2	2	-2	3	3	0	0	0	0	0	0	0	0	0	0	0	0
Soil properties	-6	1	1	-1	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Landslide and drift	-6	1	1	-1	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Surface water quality	-6	1	1	-1	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater quality	-6	1	1	-1	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Aquatic ecosystem	-6	1	1	-1	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Plant species	-6	1	1	-1	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Plant density	-4	1	1	-1	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Welfare	0	0	0	0	0	0	7	1	1	1	3	4	0	0	0	0	0	0
Health	0	0	0	0	0	0	7	1	1	1	3	4	0	0	0	0	0	0
Housing	0	0	0	0	0	0	7	1	1	1	3	4	0	0	0	0	0	0
Literacy	0	0	0	0	0	0	7	1	1	1	3	4	0	0	0	0	0	0
Physical health	0	0	0	0	0	0	7	1	1	1	3	4	0	0	0	0	0	0
Quality of life	0	0	0	0	0	0	7	1	1	1	3	4	0	0	0	0	0	0
Income level	0	0	0	0	0	0	0	0	0	0	0	0	7	1	1	1	3	4
Unemployment	0	0	0	0	0	0	0	0	0	0	0	0	-7	1	1	-1	3	4

Table 4. Evaluation of geocybernetic scores during road construction.

Component	**Geocybernetic scores**																	
	Environment						**Social**						**Economic**					
	GS (E)	**A1**	**A2**	**A3**	**B1**	**B2**	**GS (S)**	**A1**	**A2**	**A3**	**B1**	**B2**	**GS (Ec)**	**A1**	**A2**	**A3**	**B1**	**B2**
Impact of excavation on noise	-8	1	2	-1	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Impact of excavation on erosion	-108	3	3	-3	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Impact of earthworks on drainage	-162	3	3	-3	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of earthworks on topography	-108	3	3	-2	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of earthworks on air pollution	-30	2	3	-1	3	2	0	0	0	0	0	0	0	0	0	0	0	0
Impact of earthworks on noise pollution	-24	2	3	-1	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Impact of earthworks on Surface water quality	-162	3	3	-3	3	3	0	0	0	0	0	0	0	0	0	0	0	0
Impact of herbicides on Surface water quality	-162	3	3	-3	3	3	0	0	0	0	0	0	0	0	0	0	0	0
Impact of loading of Materials on noise	-5	1	1	-1	3	2	0	0	0	0	0	0	0	0	0	0	0	0
Impact of road shoulder Construction on soil erosion	-8	1	2	-1	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Impact of compaction on soil erosion	-8	1	2	-1	2	2	0	0	0	0	0	0	0	0	0	0	0	0
River bank erosion	-8	1	2	-1	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Degradation of roadside lands	-32	2	2	-2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Slope failure	-48	3	2	-2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Impact of clearing on Terrestrial ecosystem	-20	2	2	-1	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Impact of explosion on animal habitat	-90	3	3	-2	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Impact of bedding and pavement on animal habitat	-10	1	2	-1	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Impact of bridge construction on aquatic ecosystem	-48	2	2	-2	2	4	0	0	0	0	0	0	0	0	0	0	0	0

Component	Geocybernetic scores																	
	Environment						Social						Economic					
	GS (E)	A1	A2	A3	B1	B2	GS (S)	A1	A2	A3	B1	B2	GS (Ec)	A1	A2	A3	B1	B2
Impact on trees	-20	2	2	-1	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Impact on wildlife	-40	2	2	-2	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Noise for local communities	0	0	0	0	0	0	-8	1	2	-1	2	2	0	0	0	0	0	0
Impact of employment on public participation	0	0	0	0	0	0	135	3	3	3	2	3	0	0	0	0	0	0
Impact of employment on population density	0	0	0	0	0	0	40	2	2	2	2	3	0	0	0	0	0	0
Impact of manpower on regional income	0	0	0	0	0	0	0	0	0	0	0	0	135	3	3	3	3	2
Cost of land use change	0	0	0	0	0	0	0	0	0	0	0	0	-30	1	3	-2	3	2
Road construction cost	0	0	0	0	0	0	0	0	0	0	0	0	-90	3	2	-3	3	2
Impact of construction operations on tourism	0	0	0	0	0	0	0	0	0	0	0	0	-5	1	1	-1	3	2

Table 5 shows an evaluation of geocybernetic scores after road construction. Among geocybernetic scores, the highest score was associated with the economic geocybernetic score of the reduced cost of timber and the lowest scores were with the environmental geocybernetic score of Impact of machinery traffic on surface water quality, the impact of waste transport on terrestrial ecosystem and impact of waste transport on aquatic ecosystem. The impact of road construction on economic exchanges between villages and cities can increase the economic score in this assessment.

Table 5. Evaluation of geocybernetic scores after road construction.

Component	Geocybernetic scores																	
	Environment						Social						Economic					
	GS (E)	A1	A2	A3	B1	B2	GS (S)	A1	A2	A3	B1	B2	GS (Ec)	A1	A2	A3	B1	B2
Impact of machinery traffic on air	-56	2	2	-2	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of machinery traffic on noise	-56	2	2	-2	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of machinery traffic on microclimate	-56	2	2	-2	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of machinery traffic on sedimentation	-126	3	3	-2	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of machinery traffic on soil erosion	-126	3	3	-2	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of machinery traffic on surface water quality	-189	3	3	-3	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of waste transport on Terrestrial Ecosystem	-189	3	3	-3	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of waste transport on aquatic ecosystem	-189	3	3	-3	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of machinery traffic on terrestrial ecosystem	-56	2	2	-2	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of machinery traffic on aquatic ecosystem	-56	2	2	-2	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of road on landscape	-12	1	2	-1	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of machinery traffic on plant habitat	-12	1	2	-1	2	4	0	0	0	0	0	0	0	0	0	0	0	0
Impact of road on development of forestry management plans	0	0	0	0	0	0	189	3	3	+3	3	4	0	0	0	0	0	0
Impact of road on increasing conservation of forest	0	0	0	0	0	0	189	3	3	+3	3	4	0	0	0	0	0	0
Impact of road on increasing services to upstream villages	0	0	0	0	0	0	189	3	3	+3	3	4	0	0	0	0	0	0
Impact of road on population of the region	0	0	0	0	0	0	189	3	3	+3	3	4	0	0	0	0	0	0
Impact of road on regional tourism	0	0	0	0	0	0	189	3	3	+3	3	4	189	3	3	+3	3	4
Employment of manpower	0	0	0	0	0	0	0	0	0	0	0	0	189	3	3	+3	3	4
Reduced cost of timber	0	0	0	0	0	0	0	0	0	0	0	0	216	3	3	+3	4	4
Transit of goods to upstream villages	0	0	0	0	0	0	0	0	0	0	0	0	189	3	3	+3	3	4

Auffret & Lindgren (2020), Deljouei et al. (2018) and Senturk et al. (2018) reported that road construction facilitates the achievement of management goals including forest protection but there are some negative environmental impacts similar to the road construction stage. The movement of heavy machinery in the forest leads to major soil damages, which negatively affect the growth potential of the trees (Eskioglou & Efthymiou, 1998; Parsakhoo et al., 2009). The number of environmental, social, economic and total components was and 12, 5, 4, and 20, respectively. Some researchers reported that negative environmental effects of road construction will last for some decades, but usually after the first three years, they will decrease significantly because of vegetation reestablishment (Abdi & Majnounian, 2018). However, disturbance on natural drainage system will remain as a negative effect of road existence (Rahbari Sisakht et al., 2014).

Table 6 shows the final GS scores and bands for components before road construction. Average of GS (T), GS (E), GS (A), GS (S), GS (Ec) are -4.18, -5.5, 1.31, 2.62 and 0, respectively. The average number of environmental, social and economic was -5.5(-VW), 2.62 (+VW) and zero (-VW). The environmental and economic components need to reach a higher level of stability and should be considered more carefully during the project construction, by periodic inspections of road maintenance operations with environmentally friendly materials to reduce future costs, especially to prevent soil erosion in the roadbed.

Table 6. The final GS scores and bands for components before road construction.

Component	Geocybernetic scores					
	GS(T)	**GS range**	**GS(E)**	**GS(A)**	**GS(S)**	**GS(Ec)**
Soil erosion	-48	-VW	-48	0	0	0
Soil properties	-6	-VW	-6	0	0	0
Landslide and drift	-6	-VW	-6	0	0	0
Surface water quality	-6	-VW	-6	0	0	0
Groundwater quality	-6	-VW	-6	0	0	0
Aquatic ecosystem	-6	-VW	-6	0	0	0
Plant species	-6	-VW	-6	0	0	0
Plant density	-4	-VW	-4	0	0	0
Welfare	3.5	+VW	0	3.5	7	0
Health	3.5	+VW	0	3.5	7	0
Housing	3.5	+VW	0	3.5	7	0
Literacy	3.5	+VW	0	3.5	7	0
Physical health	3.5	+VW	0	3.5	7	0
Quality of life	3.5	+VW	0	3.5	7	0
Income level	3.5	+VW	0	3.5	0	7
Unemployment	-3.5	-VW	0	-3.5	0	-7
Average	-4.18	-VW	-5.5	1.31	2.62	0

Table 7 shows the final GS scores and bands for components during road construction. The highest total geocybernetic score was associated with the impact of employment on public participation and impact of manpower on regional income and the lowest total geocybernetic score was with the impact of earthworks on drainage, impact of earthworks on surface water quality and impact of herbicides on surface water quality. Average of GS (T), GS (E), GS (A), GS (S), GS (Ec) are -37.5, -40.77, 3.27, 6.18 and 0.37, respectively. The average number of environmental, social and economic was -40.77 (-VW), 6.18 (+VW) and 0.37 (-VW). The results showed that the need to reach a higher level of stability should be considered more carefully, it is even possible to cross the maximum length of the road through low-slope areas and observe the balance of embankment and excavation and cross paths without stones and rocks to prevent explosions.

Table 7. The final GS scores and bands for components during road construction.

Component	Geocybernetic scores					
	GS(T)	GS range	GS(E)	GS(A)	GS(S)	GS(Ec)
Impact of excavation on noise	-8	-VW	-8	0	0	0
Impact of excavation on erosion	-108	-VW	-108	0	0	0
Impact of earthworks on drainage	-162	-VW	-162	0	0	0
Impact of earthworks on topography	-108	-VW	-108	0	0	0
Impact of earthworks on air pollution	-30	-VW	-30	0	0	0
Impact of earthworks on noise pollution	-24	-VW	-24	0	0	0
Impact of earthworks on surface water quality	-162	-VW	-162	0	0	0
Impact of herbicides on surface water quality	-162	-VW	-162	0	0	0
Impact of loading of materials on noise	-5	-VW	-5	0	0	0
Impact of road shoulder construction on soil erosion	-8	-VW	-8	0	0	0
Impact of compaction on soil erosion	-8	-VW	-8	0	0	0
River bank erosion	-8	-VW	-8	0	0	0
Degradation of roadside lands	-32	-VW	-32	0	0	0
Slope failure	-48	-VW	-48	0	0	0
Impact of clearing on terrestrial ecosystem	-20	-VW	-20	0	0	0
Impact of explosion on animal habitat	-90	-VW	-90	0	0	0
Impact of bedding and pavement on animal habitat	-10	-VW	-10	0	0	0
Impact of bridge construction on aquatic ecosystem	-48	-VW	-48	0	0	0
Impact on trees	-20	-VW	-20	0	0	0
Impact on wildlife	-40	-VW	-40	0	0	0
Noise for local communities	-4	-VW	0	-4	-8	0
Impact of employment on public participation	67.5	+VW	0	67.5	135	0
Impact of employment on population density	20	+VW	0	20	40	0
Impact of manpower on regional income	67.5	+VW	0	67.5	0	135
Cost of land use change	-15	-VW	0	-15	0	-30
Road construction cost	-45	-VW	0	-45	0	-90
Impact of construction operations on tourism	-2.5	-VW	0	-2.5	0	-5
Average	-37.50	-VW	-40.77	3.27	6.18	0.37

Table 8 shows the final GS scores and bands for components after road construction. The highest total geocybernetic score was associated with the impact of the road on regional tourism and the lowest total geocybernetic score was with the impact of machinery traffic on surface water quality, the impact of waste transport on the terrestrial ecosystem and impact of waste transport on the aquatic ecosystem. The movement of heavy machinery in the forest leads to major soil damage, which negatively affects the growth of trees (Eskioglou & Efthymiou, 1998). Given the logging ban in the Hyrcanian forest after 2017, it seems that ecotourism is the main function of existing road networks in the north of Iran. Therefore, in recent years more studies have addressed this issue, such as Talebi et al. (2018) and Hosseini et al. (2018) who assessed the planning and evaluating criteria of forest road networks to select the optimal networks for tourism development. Caliskan (2013) suggested that forest road managers should consider not only the total road cost but also the environmental impact caused by road construction and use for sustainability. Average of GS (T), GS (E), GS (A), GS(S) and GS (Ec) are -13.35, -56.55, 43.2, 47.25 and 39.15, respectively. The average number of environmental, social, economic was -56.55 (-VW), 47.25 (+VW) and 39.15 (+VW). Ameri Golestan (2013) and Handa et al. (2019) reported that roads had more environmental negative impacts than social impacts.

Table 8. The final GS scores and bands for components after road construction.

Component	Geocybernetic scores					
	GS(T)	**GS range**	**GS(E)**	**GS(A)**	**GS(S)**	**GS(Ec)**
Impact of machinery traffic on air	-56	-VW	-56	0	0	0
Impact of machinery traffic on noise	-56	-VW	-56	0	0	0
Impact of machinery traffic on microclimate	-56	-VW	-56	0	0	0
Impact of machinery traffic on sedimentation	-126	-VW	-126	0	0	0
Impact of machinery traffic on soil erosion	-126	-VW	-126	0	0	0
Impact of machinery traffic on surface water quality	-189	-VW	-189	0	0	0
Impact of waste transport on terrestrial ecosystem	-189	-VW	-189	0	0	0
Impact of waste transport on aquatic ecosystem	-189	-VW	-189	0	0	0
Impact of machinery traffic on terrestrial ecosystem	-56	-VW	-56	0	0	0
Impact of machinery traffic on aquatic ecosystem	-56	-VW	-56	0	0	0
Impact of road on landscape	-12	-VW	-12	0	0	0
Impact of machinery traffic on plant habitat	-12	-VW	-12	0	0	0
Impact of road on development of forestry management plans	94.5	+VW	0	94.5	189	0
Impact of road on increasing conservation of forest	94.5	+VW	0	94.5	189	0
Impact of road on increasing services to upstream villages	94.5	+VW	0	94.5	189	0
Impact of road on population of the region	94.5	+VW	0	94.5	189	0
Impact of road on regional tourism	189	+VW	0	189	189	189
Employment of manpower	94.5	+VW	0	94.5	0	189
Reduced cost of timber	108	+VW	0	108	0	216
Transit of goods to upstream villages	94.5	+VW	0	94.5	0	189
Average	-13.35	-VW	-56.55	43.2	47.25	39.15

4. Conclusions

The geocybernetic economic scores before, during and after road construction are 0 (very weak unsustainability) 0 (very weak unsustainability) and 39 (very poor stability), respectively. This score has increased from before road construction to after road construction, indicating the impact of the road on economic development.

The social geocybernetic scores before, during and after road construction are 3 (very poor stability), 6 (very poor stability), and 47 (very poor stability), respectively, indicating the impact of the road on increasing social services.

Before, during and after road construction environmental geocybernetic scores were -5.5 (very weak unsustainability), -41 (very weak unsustainability), and -57 (very weak unsustainability), respectively. The lowest environmental geocybernetic score is after road construction, which indicates the negative impact of road construction on the environment. The total geocybernetic scores before, during and after road construction are -4 (very low instability), -38 (very low instability) and -13 (very low instability), respectively. As shown, the lowest total geocybernetic score is at the time of road construction, and the total geocybernetic score after road construction increases due to increased economic and social services.

Among all geocybernetic scores, the highest score was related to the after road construction social geocybernetic score and the lowest score was to the after road construction environmental geocybernetic score.

The number of environmental components before, during, and after road construction was 8, 20 and 12, respectively. There were 6, 3, and 5 social components before, during and after the road construction, respectively.

The number of economic components before, during, and after construction of the road was 2, 4, and 4, respectively. Among all components, the highest number is related to environmental components during road construction which is 20 cases and the least number of components related to economic components before road construction is 2.

Given that the total geocybernetic score was in a range of (very weak unsustainability) at all three stages before, during and after the road construction, the road construction in the area was also causing environmental impacts, but service (social and economic) has also been reported, which has left the entire geocybernetic score constant in the very weak instability range. In summary, it can be noted that the construction of the Kheyrud forest road using the GAM method has not at least worsened the stability of the region's ecosystem, and its construction has not created any instability in general.

In each of the three stages of before, during and after road construction, there are the components, which get the lowest score. In similar projects, it is necessary to consider such components before, during and after road construction to mitigate the environmental damage of road construction. Road construction based on an engineered design is the best way to assure that roads are environmentally acceptable, economically feasible and physically possible to meet the demands for which they are built.

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ارزیابی اثرات محیط زیستی جاده‌های جنگلی با استفاده از ماتریس ارزیابی ژئوسایبرنتیک مطالعه موردی جنگل خیرود

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چکیده

ارزیابی اثرات زیست محیطی (EIA) به عنوان تجزیه و تحلیل اثراتی که یک پروژه می‌تواند بر محیط زیست تحمیل کند، با هدف ایجاد تعادل بین اثرات مثبت و منفی پروژه شناخته شده است. جاده سازی در عرصه جنگلی یکی از پرهزینه‌ترین و مهم‌ترین پروژه‌هایی است که به دلیل مشارکت در توسعه عملیات‌های مختلف جنگل‌داری، نتایج آن نیاز به ارزیابی دارد. هدف از پژوهش حاضر بررسی اثرات محیط زیستی شبکه جاده در جنگل آموزشی پژوهشی خیرود نوشهر (جنگل هیرکانی) در سه مرحله قبل، حین و بعد از مرحله جاده سازی بود. در این تحقیق از معیارهای ماتریس ارزیابی ژئوسایبرنتیک (GAM) با استفاده از نظرات کارشناسانی که مشکلات مربوط به جاده سازی را در سه مرحله مشاهده کرده‌اند، از امتیازهای فهرست شده استفاده کردیم. با اعمال این روش، ابزار مناسبی برای اطمینان از اجرای صحیح پروژه و یا توقف آن به دست می‌آید. یافته‌های این ارزیابی می‌تواند روشی برای تعیین، پیش‌بینی و تفسیر اثرات محیط زیستی، اجتماعی و اقتصادی ساخت و ساز جاده بر کل محیط زیست و سلامت اکوسیستم‌هایی باشد که حیات و پایداری انسان به آن بستگی دارد. نتایج نشان داد که نمره کل ژئوسایبرنتیک در محدوده ۰ تا ۱۲۱- (ناپایداری بسیار ضعیف) برای قبل، حین و بعد از راه‌سازی قرار دارد که نشان می‌دهد اگرچه جاده‌سازی جنگلی خیرود تأثیرات منفی بر محیط‌زیست به‌ویژه در حین جاده‌سازی داشته است. خدمات اجتماعی و اقتصادی، به ویژه پس از ساخت جاده، مجموع امتیاز ژئوسایبرنتیک را در آن محدوده باقی گذاشته است.

واژه‌های کلیدی: ماتریس ارزیابی، رابطه انسان- محیط زیست، ارزیابی اثررات محیط زیستی، پایداری.

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