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Roads impact assessment on wildlife habitats using Leopold matrix for mitigations: A case study in Darmian protected area

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ABSTRACT

The impact of roads as ubiquitous features of the modern landscape on wildlife habitat and biodiversity is now a serious global concern. In this regard, biodiversity has become a major environmental issue to promote sustainable development; due to transportation infrastructure around the world, habitat loss is now considered a major threat to biodiversity conservation. The development of communication roads has exerted devastating influences on the environment, especially on wildlife habitats and sensitive ecosystems. This catastrophe is unfortunately spreading in Iran. Therefore, the purpose of this paper is to assess the impacts of the Darmian road which passes through the middle of a protected area and divides it into two southeast and northwest parts. The Leopold matrix method was used to identify potential impacts on wildlife habitats. The scoring process in the Leopold matrix was performed by collecting the opinions of a panel of environmental experts and specialists based on the criteria of magnitude and significance. The results of importance risks showed that vehicle traffic (244), vehicle traffic noise (67), salt defrosting (39), light attraction and attention (24), and warm road surfaces (21) have the greatest impacts on the environment, respectively. Also, the evaluation of environmental factors showed that the highest risks due to road functions include fragmentation and reduction of the habitat area (68), greater access to natural ecosystems (63), noise pollution (53), hunting and reduced habitat safety (44), and wildlife fatalities and accidents on roads (34). It showed that the exploitation of Darmian road has always caused negative impacts. It is inferred that, the environmental managers should pay more attention to the use of mitigation measures as management strategies to decrease the amount of negative impacts and further damage in the future. Finally, management strategies and solutions are suggested to reduce environmental damage according to the important impacts of road exploitation.

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1. Introduction

The roads and traffic are the distinctive features of man-made and up-to-date landscapes. Thus, the impact of roads on biodiversity has become a major concern around the world, while road networks are growing in most parts of the world. The impacts of road factors on species varies from species to species, or from one geographical area to another due to biodiversity in the environment and diversity in the physical characteristics of roads. In order to determine the type of effect for each species, it is necessary to conduct many studies on different types of species in different conditions (Taylor and Goldingay, 2010).

The fragmentation of habitat landscapes due to transportation infrastructure such as roads is a growing concern among ecologists and civil engineers. There are extended evidences of the complex impact of these factors on biodiversity, wildlife and landscape (Seiler, 2001).

Most wildlife populations are at greater risk of population decline and extinction when their habitats are fragmented by roads. So the important question is how are such roadside threats considered in environmental impact assessment (EIA) and road planning? The purpose of the EIA is to identify and systematically evaluate the potential impacts of proposed projects to ensure environmental protection and sustainable development (Jaeger, 2015). However, there are many uncertainties about the ecological impact of roads on the potential landscape scale, for example the effects of road network configuration on wildlife populations. Roads are change factors that have primary or direct effects and secondary or indirect effects on biota (Bennett, 1991). Roads directly affect the population of animals and plants by destroying and cutting off moving paths. While for some species the destruction of a small area for the road bed may not be significant, for some species, especially small animals with high levels of site fidelity, it can be devastating. Crowds of animals move slowly, and those who cross the road regularly suffer particularly from the negative effects of increased vehicle collision mortality. Roads also act as a conduit for introducing and facilitating the spread of exotic species. Indirect road effects include changes or impacts resulting from raised human reference and land use actions. Roads are agents of change that have both primary, or direct impacts, as well as secondary, or indirect impacts on the biota (Bennett, 1991). Roads affect animal and plant populations directly by entirely obliterating the ecosystems in their path. While for some species, the destruction of a small area for a roadbed may not be significant, for some species, particularly small animals with high levels of site fidelity, it can be ruinous. Populations of slow moving animals and those which regularly cross roads suffer in particular from the negative impacts of increased mortality due to vehicle collisions. Roads also act as conduits introducing and facilitating the spread of exotic species. The indirect impacts of roads include changes or impacts that result from increased contact with humans and human land use activities (Coffin, 2007). Road factors and traffic infrastructure directly and indirectly affect natural landscapes. The presence of structures such as roads, railways, and energy transmission lines in the landscape creates new marginal habitats, altering hydrological dynamics, and disrupting natural processes and habitats. During the operation of these infrastructures, their environment is exposed to a variety of chemical and noise pollutants. In addition, roads and traffic lanes prevent the dispersal of many animals other than birds, killing millions of animals across the roads each year. In addition to destroying wildlife, these structures cause habitat isolation due to fragmentation of habitat landscapes (Figure 1). Secondary impacts i.e land use/cover changes, urban growth, development of the mineral, and industrial zones, or exploitation of the natural resource needs for the construction of contemporary structures such as roads or railroads. researchers determined five principal classes of preliminary ecological consequences (Bennett, 1991; Van der Zande, Ter Keurs and Van der Weijden, 1980; Wilson and Forman, 1995):

1. The building of roads and railways always involves the destruction of habitat landscapes and the reduction of biodiversity. Human processes of land conversion and change lead to many disturbances in habitat integrity.
2. Turbulence due to pollution and edge effects - Along the way of roads and railways, the natural environment encounters a variety of pollutants that include not only the width of the road but also a much wider area affected by the effects of its operation known as an/a edge/marginal effect.
3. Corridors - Roads and side roads can be refuges, temporary habitats, steping stones or moving corridors for wildlife. But the beneficial effects of this infrastructure are a major challenge for planners and biologists, as management and design must adapt a matrix of landscape to a new road entity.
4. Traffic and hunting deaths - Vehicle traffic is the cause of death for many animals that use marginal habitats or cross roads or railroads to meet their needs.
5. Barrier - For most non-flying land animals, infrastructure includes movement barriers that limit the range of animals, make habitats inaccessible, and can ultimately lead to population isolation. Barrier impact is the most prominent factor in the overall fragmentation of infrastructure. Road infrastructure and traffic routes prevent the dispersal of many animals other than birds, and ultimately isolate their populations through habitat fragmentation.

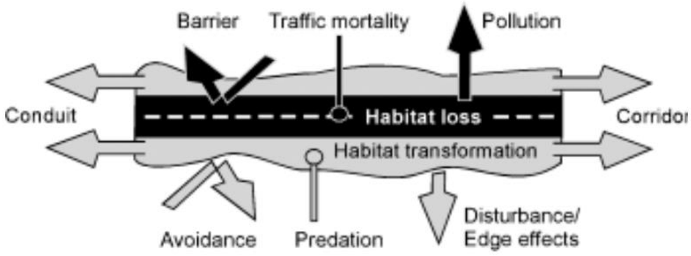

Fig. 1. Schematic illustration of the five principal classes of preliminary ecological consequences of infrastructure (Seiler, 2001; Van der Zande et al., 1980).

The development of communication roads has devastating impacts on the environment, especially their construction in wildlife habitats and sensitive ecosystems, which is a catastrophe that is unfortunately spreading in Iran. This paper aimed to assess the impacts of the road, especially the Birjand-Sarbisheh main road, which passes through the middle of the protected area and divides it into two parts, southeast and northwest. There is a lot of research on environmental impact assessment on wildlife habitats and biodiversity over the past decades around the world based on different frameworks. One paper described the results of an additional study of numerous EISs were assembled between 1993-1997 and also reviewed recent changes in the political context for EIA of proposed road developments, including developments in UK transport policy and the UK biodiversity process. The results of this study recommended that the ecological assessment of proposed road developments has enhanced in some regards, but also spotlights the continuation of multiple flaws in before studies (Byron, Treweek and William, 2000). Geneletti (2003) presented a method for the Biodiversity Impact Assessment (BIA) of road assignments that concentrates on the direct loss of ecosystems. The first phase of this study involved mapping the different types of ecosystems and then assessing their relationship to biodiversity conservation. This study was used to evaluate alternative routes for highway development in northern Italy (Geneletti, 2003). Taylor et al. (2010) reviewed the recent literature (244 published studies) on road impacts on wildlife, to identify gaps in understanding of this topic and to guide future research and management in Australia. Karlson et al. (2014) conducted a study to review methods to deal with environmental impacts in the environmental assessment of transportation infrastructure projects. They reached to 17 classes of biodiversity improvement strategies that were formulated using content analysis. The results show that despite significant improvements over the years, some effects are still problematic. Measures to improve environmental impact can include improved guidelines for determining spatial and temporal boundaries, and the creation of a quantitative framework including tools, methods, and threshold values (Karlson et al., 2014). In a study was analyzed the probable impacts of roads on maned wolf population size and landscape structure. Researchers utilized a model to estimate the population-scale effects of individual manned wolf relations with roads, which can result in road crossing, avoidance, or mortality due to a collision with a vehicle (Barbosa et al., 2020). In Iran, several research studies have been conducted on the environmental impact of roads. In a study by Tavakoli and Sabetraftar (2003), the positive and negative consequences of the Anzali Bypass Road project on the sensitive ecosystem of Anzali Wetland have been evaluated using a simple matrix. The results showed that the project implementation is possible only if there is an economic justification, and/or improvement plans are presented. The Environmental Impact Assessment (EIA) of Qomishloo freeway construction using ICOLD matrix and checklist was performed by Falahatkar, Sadeghi, and Soffianian, (2010). The results showed that the passage of this freeway through Qomishloo wildlife refuge will cause damage to the environment of the region, thus this project was aborted. Considering the role of Golestan forest road, some studies were applied on the impacts of traffic noise pollution on the bird communities in Golestan National Park (Gharibi, Salmanmahiny and Varasteh, 2014) and the impact on the diversity and pattern of wildlife road casualties (Hemami, 2017). In order to evaluate the impacts of Eastern Hamadan Beltway, two proposed options or paths were examined using Rapid Impact Assessment Matrix (RIAM), TOPSIS, and Analytical Network Process (ANP) by

Amini, Mehrdadi, Karami, Givehchi, and Hoveidi (2014). The Results showed that the best method and the recommended options were ANP method and the first path, respectively. The EIA resulting from the construction of Shahid Sadr Expressway in Tehran while still at construction and operation phases was conducted by coding the modified Leopold matrix (Iranian matrix) methods. Results revealed that the road project has positive impacts during the operation phase, but negative impacts during the construction phase.

2. Material and Methods

2.1. Description of Darmian Protected Area

Darmian Protected Area, with an area of 79311 hectares, is located in the eastern parts of Iran and stands at a distance of 68 km from Birjand city and 25 km north of Sarbisheh city in South Khorasan province. The geographical location of the study area spans between 59º 40' to 60º 1' eastern longitudes and 32 º 36' to 32º 58' northern latitudes with an average height of 1950 meters (Figure 2). Darmian Protected Area is located in arid and semi-arid regions and almost all kinds of natural phenomena such as mountains, hills, springs, rivers and various aqueducts can be found there. The region has a hot and dry climate, but a more temperate climate in mountainous areas due to rain and snow. The topography of the area is mainly mountainous and rocky and in some parts, it is hilly. The rangelands of this area have 27 separable plant types. Existence of numerous springs, and diverse and high quality rangeland vegetation have provided a suitable habitat for several species of animals. Of the most important species, one can refer to Ovis orientalis, Alectoris chukar, Falco tinnunculus, Gypaetus, barbatus, and Uromastym aegyptus. Deer can also be found in this area, but with a scattered population, limited and endangered. There are 50 natural springs in the Sarbisheh Protected Area, as well as artificial springs which include the region's aqueducts and water wells, however, due to the presence of local people during the day, these springs are less frequently used by the wildlife. Water resources constitute one of the most important ecological reserves on which the distribution of wildlife depends a lot. There are five villages inside the area and 35 villages on the outskirts of the protected area. Birjand Sarbisheh main road passes through the middle of the region so that it divides the region into two southeast and northwest halves.

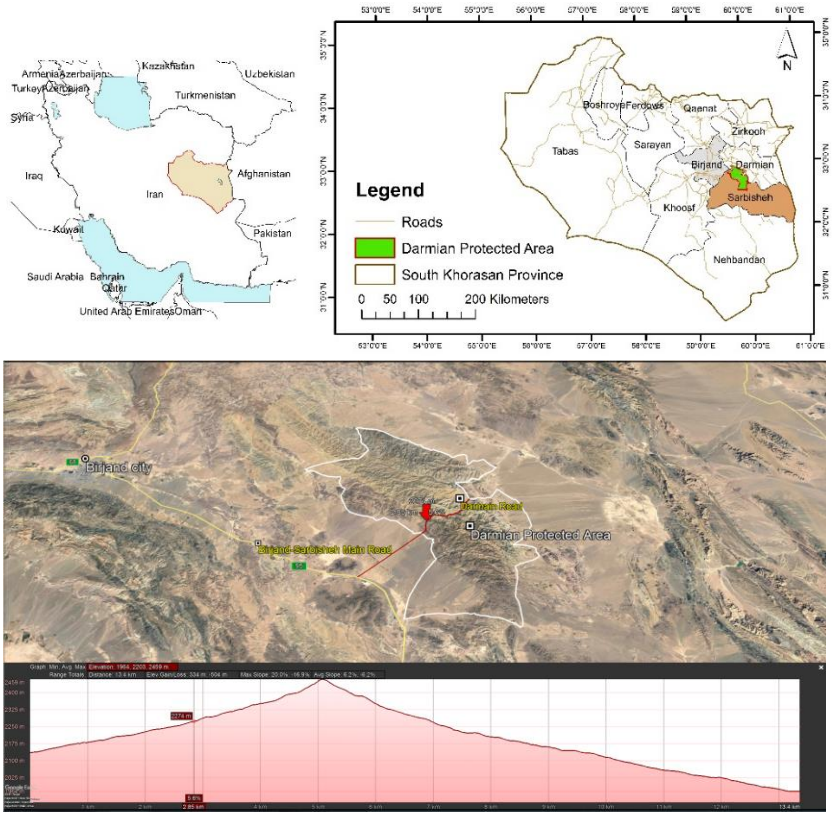

Fig. 2. Map of the study area and location of Darmain road in protected area

2.2. Research Methods

In the present study, the Leopold matrix method was used to identify the potential impacts on wildlife habitats. This method was developed by Leopold (1971). The Leopold matrix is a two-dimensional reciprocal matrix whose columns represent project-related activities that may affect humans and the environment. And matrix rows represent environmental and social conditions that could potentially affect the project (Al-Nasrawi et al., 2020). The impact of the action columns and the environmental condition row are detemind in terms of its magnitude and significance. Each action and its potential impacts on each of the environmental items was taken into account. The magnitude of the interaction (extensiveness or scale) was described by the assigned values ranging from 1 (for small magnitudes) to 10 (for large magnitudes). The allocation of numeric values was performed based on assessment the accessible evidence and information. In the same way, the extent of importance ranged from 1 (very low interact) to 10 (very essential interact). Nevertheless, the allocation of numeric values for the scale of magnitude was based on the subjective decision of the cross-disciplinary team of the EIA survey (Doutora Maria do Rosário Partidário, 2011). The following steps were followed to construct the Road Impacts Assessment Leopold matrix:

1. Identifying all associated actions of Darmian road in the term of magnitude;
2. Identifying all affected environmental components of Darmian road in term of significance;
3. Placing a slash diagonally from upper-right to lower-left of each block to represent important interaction; Figure (3) shows the general form of each Leopold matrix box.

	Actions causing impacts					
Environmental components		A_1	A_2	…	A_n	Sum
	E_1	M / S				$I = \sum M_1 * S_1$
	E_2					$I = \sum M_2 * S_2$
	…					
	E_m					$I = \sum M_n * S_m$
	Sum	$I = \sum M_1 * S_1$	$I = \sum M_1 * S_2$		$I = \sum M_n * S_m$	

M: Magnitude, S: Significance, I: Importance

Fig. 3. General form of the Leopold Matrix

The Leopold matrix approach has resoneable flexibility. Rows and columns can be increased or decreased depending on the nature and scope of the study based on which the environmental impacts are assessed, depending on the number of activities and environmental components. This aspect creates a distinctive and attractive feature for the Leopold matrix. Technically, the Leopold matrix approach is a process for screening effects that are identified firstly. This approach is a valuable tool for explaining the effects by providing a visual representation of the effects and their causes. Calculating the values of interactive rows and columns can provide deeper insights into the effects and help to further interpret the consequences (Doutora Maria do Rosário Partidário, 2011).

3. Results and discussion

The Leopold matrix framework has been used in this study, to investigate the effects of exploiting the Darmian road in the protected area of Darmian, and to reduce the negative impacts and provide solutions for improvement. According to the research methodology, first, the functions resulting from road activities (project exploitation) and the possible impacts on the environmental components were identified through recognizing the study area and brainstorming. Some of these components are illustrated in Figure 4 on the Darmian road.

Land subsidence

wildlife fatalities and accidents

The recreational site of Ab-e-torsh

Hunting

Fig. 4. The pictures of environmental components and road activities

Road activities included vehicle traffic, vehicle traffic noise, salt defrosting, light attraction and attention, and warm road surfaces. Salt sprayed on the road surfaces to ease defrosting draws wildlife to the roads. This salt can be lethal to wildlife, especially mammals and birds. The warm surface of the roads also plays an important role in attracting animals. The identified potential environmental components affected included: wildlife fatalities and accidents on roads, hunting and reduced habitat safety, habitat fragmentation, habitat reduction, marginal impacts on vegetation, air pollution, impact on water quality, noise pollution, impact on structure and function of ecosystems, soil erosion and compaction, roadside waste accumulation and greater access to natural ecosystems. The evaluation and scoring process in the Leopold matrix was performed by collecting the opinions of a panel of environmental experts and specialists based on the criteria of magnitude and significance of the work (Table 1). Also, the priority of impacts or importance risks were obtained by multiplying the magnitude and significance criteria as described in Table 1.

Table 1. Evaluation and scoring process of environmental experts and specialists panel

		Road activities					
		Vehicle traffic	Vehicle traffic noise	Salt defrosting	Light attraction and attention	Warm road surfaces	Cumulative impacts
Environmental components	Wildlife fatalities and accidents on roads	2 / 5		2 / 3	3 / 4	2 / 3	
		10		6	12	6	***34***
	Hunting and reduced habitat safety	6 / 4		2 / 2	5 / 2	2 / 3	
		24		4	10	6	***44***
	Habitat fragmentation & habitat reduction	4 / 9	4 / 8				
		36	32				***68***
	Marginal impact on vegetation	6 / 4		2 / 4			
		24		8			***32***
	Air pollution	3 / 4					
		12					***12***

	Impact on water quality	2 / 4		3 / 7			
		8		21			***29***
	Noise pollution	3 / 6	5 / 7				
		18	35				***53***
	Impact on structure and function of ecosystems	3 / 5			1 / 2	3 / 3	
		15			2	9	***26***
	Soil erosion and compaction	2 / 5					
		10					***10***
	Roadside waste accumulation	4 / 6					
		24					***24***
	Greater access to natural ecosystems	7 / 9					
		63					***63***
	Cumulative impacts	***244***	***67***	***39***	***24***	***21***	

Therefore, by implementing this method, the importance of the negative impacts of road activities was determined. The results showed that vehicle traffic, vehicle traffic noise, salt defrosting, light attraction and attention, and warm road surfaces have the greatest impacts on the environment, respectively (Figure 5).

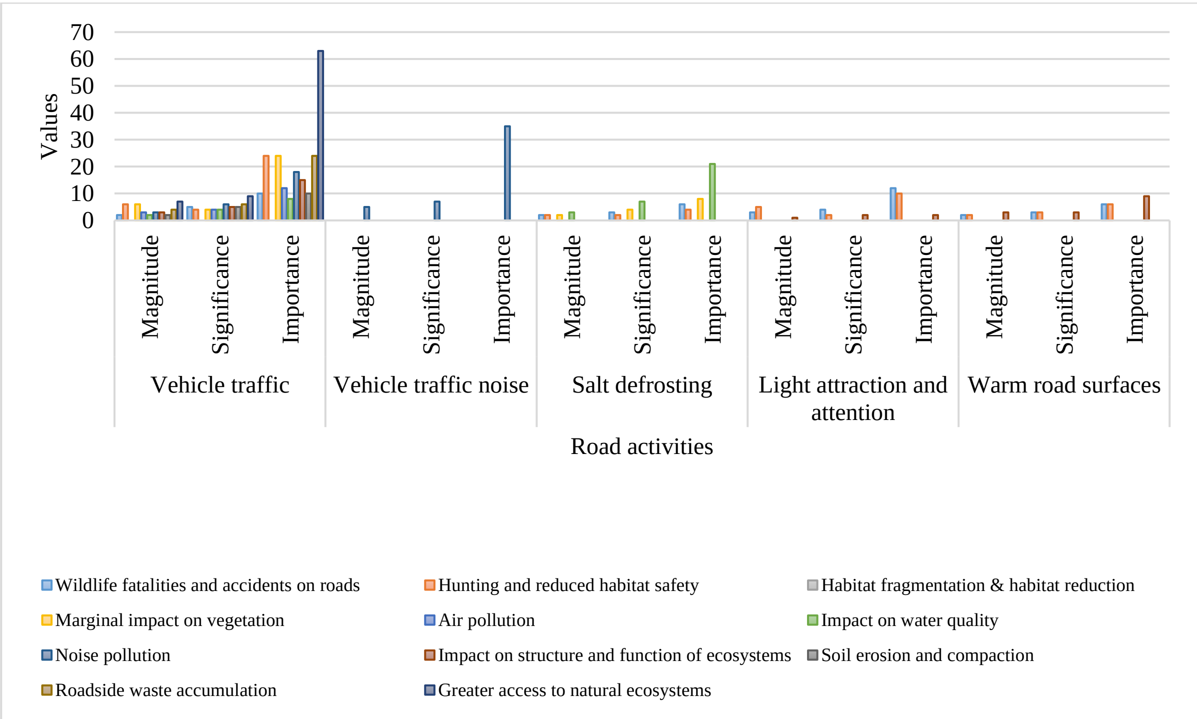

Fig. 5. Importance of the negative impacts of road activities

Also, the evaluation of environmental factors showed that the highest risks due to road functions include fragmentation and reduction of habitat area, greater access to natural ecosystems, noise pollution, hunting and reduced habitat safety, and wildlife fatalities and accidents on roads, respectively. Figure 6 also shows the risk importance and their priority in term of rank.

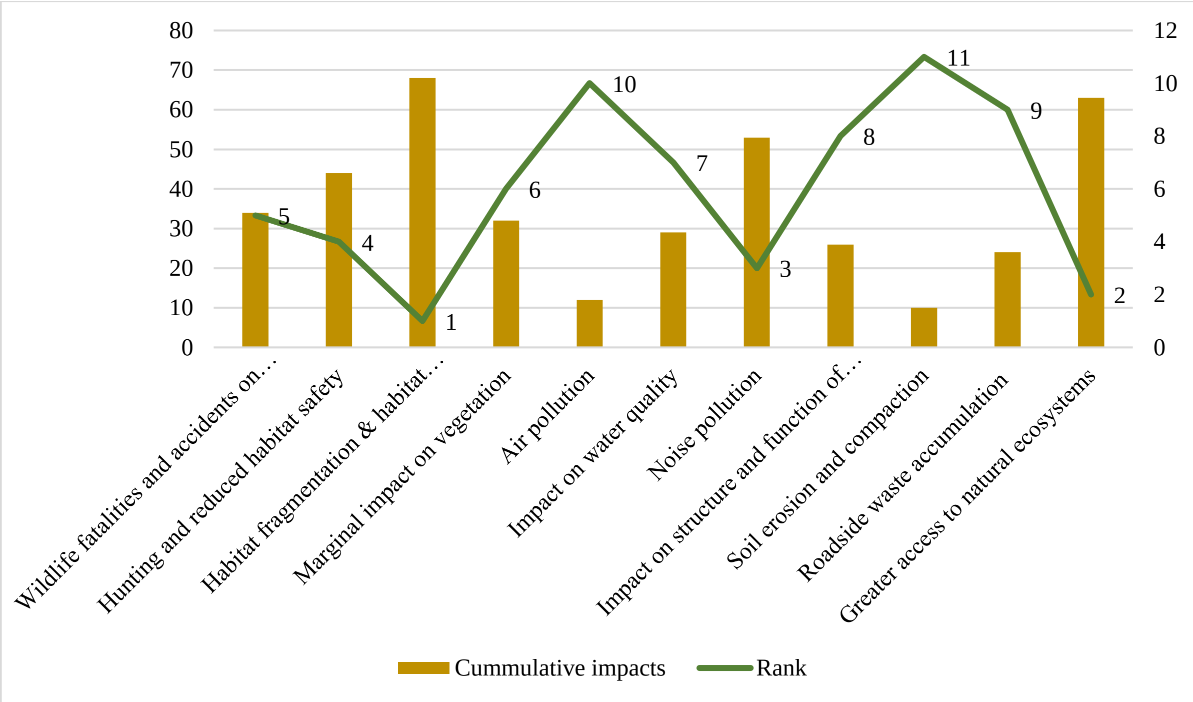

Fig. 6. Risk importance and their priority in term of rank

3.1. Discussion

One of the most important reasons for population decline in the protected area is the construction of roads and the development of recreational areas such as Ab-e-torsh treatment area. These areas create a heavy traffic for non-natives and sometimes encourage them to hunt in the area. Installation of telecommunication and satellite towers, and gas transmission line is another cause of destruction in the region. Based on the importance and priorities obtained from the EIA process, mitigation measures are presented in Table 2. According to the EIA results, habitat fragmentation and habitat reduction are recognized as the most influenced phenomena of the road impact. So, two corrective strategies are proposed: a) construction of overpasses and underpasses to enable the establishment of communication between fragmented habitats and b) controlling and monitoring sensitive areas, especially in sensitive biological periods of wildlife. It should be noted that in order to select the construction sites for overpasses and underpasses, it is necessary to study the habitat network and wildlife movement routes and find the most influential corridors. It will be useful to obtain accurate statistics and information about the number of accidents, and time and season of movements alongside the road, to understand the reasons for the wildlife movement, whether searching for food or shelter, on both sides of the road. It was mentioned earlier that recreational developments led to more traffic and, consequently, more invasion of the natural ecosystems within the protected area. Therefore, it is suggested that management plans of protected areas should be reviewed along with the determination and design of various zones, including recreational zones. In this regard, it is necessary to consider the capacity of the environment, the number of tourists and the amount of tourists' environmental education. To reduce the impacts of noise pollution and it's imping on wildlife in the region, planting medium and tall deciduous plants and trees and dense vegetation around the road can be beneficial. Decommissioning of the pollutant vehicles also helps to reduce various types of pollutions. Two measures to prevent hunting and establish habitat security are proposed. The first is to create appropriate posts for the deployment of security guards. The second is to clear the roads of weeds, shrubs, carcasses, garbage, and anything possibly attractive to invite wildlife to the road. Dealing with casualties and road accidents is possible through identifying habitat hotspots and intersecting them with accident hotspots. Favorable warning signs should be installed in accident-prone areas (critical areas) or overpasses and underpasses with suitable width for moving between fragmented habitats should be created. One of the considerations for the construction of passages and corridors for wildlife is that the overpass structure should be the most similar to the wildlife habitat in order to support the provision of habitat functions through plant species composition.

Table 2. Proposed mitigation measures as management strategies packs

Rank	Impacts	Mitigation measures (management strategies packs)
1	Habitat fragmentation & habitat reduction	✓ Construction of overpasses and underpasses to establish communication between fragmented habitats ✓ Control and monitoring of sensitive areas, especially in sensitive biological periods of wildlife.
2	Greater access to natural ecosystems	✓ Proper design of recreation area in Darmian protected area ✓ Public education and public awareness of the value of sensitive and vulnerable ecosystems
3	Noise pollution	✓ Planting medium and tall deciduous plants and trees and dense vegetation ✓ Decommissioning of used pollutant vehicles
4	Hunting and reduced habitat safety	✓ Strict control and creation of appropriate posts for the deployment of security guards ✓ clear the roads of weeds, shrubs, carcasses, garbage, and everything affected in attracting wildlife to the road
5	Wildlife fatalities and accidents on roads	✓ Identify habitat hotspots and its intersection with accident hotspots ✓ Install warning signs to drivers in the passage of wildlife
6	Marginal impact on vegetation	✓ Covering eroded surfaces around roads with vegetation ✓ Planting plants especially in areas sensitive to erosion
7	Impact on water quality	✓ Controlling the flow rate of surface water and runoff, especially on slopes leading to the road ✓ Creating sedimentation ponds of fine particles and pollutants from road surface runoff
8	Impact on structure and function of ecosystems	✓ Restoration and rehabilitation of degraded areas using native plant species ✓ Wildlife breeding and habitat improvement
9	Roadside waste accumulation	✓ Consider proper trash cans along the route, especially stopping vehicles ✓ Timely transfer of waste to landfills
10	Air pollution	✓ Covering the load of vehicles carrying materials ✓ Allowing healthy and flawless machine traffic on Darmian road
11	Greater access to natural ecosystems	✓ Reinforce slopes and excavated pits to prevent falls and erosion ✓ Improve drainage and avoid excessive accumulation and concentration of water in one direction

The results of this research showed that the exploitation of Darmian road has always faced negative impacts. The findings are highly consistent with the studies conducted in this field (Delnavaz and Khalesi, 2016; Falahatkar et al., 2010). But what environmental managers face and should pay attention to is the use of mitigation measures in the form of management strategies to prevent further impacts and damage in the future. The current study recommends management strategies through introducing the important impacts of road exploitation and solutions that can help reduce the environmental damage. The corrective solutions proposed in this research confirm the results of previous studies (Abbaspour et al., 2010; Reyazi et al., 2007) and show consistent results.

4. Conclusion

The present study investigated one of the environmental problems which has unfortunately turned into an expanding catastrophe in Iran. The observed problem was the issue of road development in a protected area, which engenders negative consequences for wildlife habitats and sensitive ecosystems. This serious danger and its future negative consequences in other areas were neglected, and no plans have so far been developed to mitigate these effects. It is a misfortune that even some people feel satisfied with the shrinking of the borders of natural areas and passively accept the adverse impacts of roads. But in the present study, the Leopold matrix method was performed to identify potential negative impacts on wildlife habitats. Therefore, by implementing this method, the importance of the negative impacts of road activities was determined. Then, based on the importance and priorities obtained from the EIA process, mitigation measure packs in terms of 20 management strategies were presented. Using these packs within time and cost constraints can be beneficial for managers of natural areas and wildlife habitats. However, ignoring the adverse consequences of roads and related activities can cause a lot of damage in the region.

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