



Sustainable Landscape Design of the Karaj-Qazvin Freeway for Enhancing Safety and Maintaining Habitat Connectivity

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Article Info	ABSTRACT
Article type: Research Article Article history: Received: 2026/02/22 Received in revised form: 2026/04/13 Accepted: 2026/04/28 Available online: 2026/06/01 Keywords: Road safety, Habitat analysis, Wildlife casualties, Ecological corridor, Freeway design.	Freeway networks are essential for transportation efficiency, but they often generate adverse consequences, including increased public safety risks and fragmentation of natural habitats. This study aimed to enhance safety for both human and wildlife populations along the Karaj–Qazvin Freeway by proposing ecologically sensitive and safety-oriented landscape interventions. The study adopted a descriptive–analytical approach combining a systematic literature review, case study selection, and extensive field investigations. The Karaj–Qazvin Freeway was selected as the study area because of its strategic importance, high traffic volume, and its location within a region with significant wildlife presence and a history of road-related accidents. Data were collected through documentary and field survey methods. Documentary sources included traffic accident reports, environmental impact assessments, and previous transportation studies. Field surveys involved direct observation of traffic patterns, identification of wildlife crossing points, and documentation of existing landscape features. A segmented SWOT analysis was employed to identify strengths, weaknesses, opportunities, and threats within different freeway sections. This analytical tool helped in formulating appropriate design strategies tailored to the specific conditions of each segment. The findings indicated that integrating wildlife underpasses, dedicated pedestrian overpasses, and protective barriers combined with guiding vegetation can substantially improve road safety and ecological performance. Wildlife underpasses allow animals to cross safely beneath the freeway, reducing the risk of collisions. Pedestrian overpasses provide safe crossing points for local communities, minimizing human casualties. Protective barriers and guiding vegetation direct both wildlife and pedestrians toward designated crossing structures. Based on the identified needs and environmental conditions, a section of the freeway was redesigned according to engineering and ecological standards. The proposed interventions are expected to reduce wildlife–vehicle collisions and traffic accidents while improving habitat connectivity. The results demonstrate that incorporating ecological principles into freeway landscape design can effectively balance transportation functions with environmental conservation objectives. Such integrated approaches contribute to biodiversity protection, enhance landscape resilience, and promote sustainable transportation infrastructure. This study provides practical recommendations for planners and decision-makers involved in highway development projects in similar ecological contexts.

Introduction

Although the development of freeway networks plays a vital role in facilitating transportation and intercity communication, it is often accompanied by unintended environmental consequences, including habitat fragmentation, wildlife–vehicle collisions, noise and air pollution, and reduced user safety. In Iran, roads are historically perceived not only as transit routes but also as cultural and spatial corridors with distinct identities. However, contemporary freeway design has largely prioritized traffic engineering criteria, often overlooking ecological, aesthetic, and experiential dimensions. This has resulted in ecological disruption, increased wildlife accidents, degraded landscape quality, and reduced user satisfaction. The Karaj–Qazvin Freeway, which passes through foothills, agricultural lands, and settlements, represents a clear example of the conflict between transportation efficiency and environmental considerations. Known as one of the most accident-prone freeways in Iran, it highlights the urgent need to reconsider current design approaches. Key research gaps include the lack of integrated studies addressing safety, sustainability, and habitat restoration simultaneously, limited quantitative evaluation of wildlife crossing effectiveness, and insufficient attention to the cultural and visual functions of freeway landscapes. The main objective of this study is to develop a practical framework for the landscape design of the Karaj–Qazvin Freeway, transforming it into a multifunctional ecological corridor that enhances wildlife safety, resident safety, user safety, and habitat continuity. The significance of this research lies in integrating road ecology, sustainable landscape design, and traffic safety principles to provide a context-sensitive model that can be applied to other freeways in Iran.

Method

This research was implemented in five consecutive steps using a combined approach based on context-sensitive design. In the first step, the Karaj–Qazvin Freeway was selected as a case study due to its unique features, including passing through natural and agricultural areas, proximity to metropolises, and high biodiversity. In the second step, extensive library studies were conducted on reputable domestic and international sources in the fields of road ecology, sustainable landscape design, traffic safety, and ecological corridors to identify and formulate the theoretical foundations and background of the research. In the third step, a comprehensive field survey was conducted along the entire 13.3 km freeway route, which included systematic photography, documentation of landscape elements (skyline, building facades, visual quality, walls, vegetation, and adjacent uses), and recording the precise location of natural and man-made features. In the fourth step, using field data and base maps, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted for the entire route as well as for its various sections (based on the division into sections A, B, and C), and the potential and design constraints in each section were identified. To increase the accuracy of the analysis, adjacent uses were classified into eight main categories (parks, intersections, private gardens, rivers, wastelands, agricultural lands, industrial areas, and religious sites) and the location of each was tracked and recorded. In the fifth step, based on the findings of the analysis, design strategies were developed for each section, and then a section of the freeway (including the linear park and the riverfront) as an example reached the executive design stage, and 2D maps and planting plans were prepared. The data analysis method was qualitative-analytical and combined field observations, library documents, and standard design criteria. The main limitation of the research was the lack of access to accurate wildlife accident statistics and long-term traffic data along the route, which was partially compensated by field observations and qualitative analyses.

Results

The field survey and SWOT analysis of the Karaj–Qazvin freeway identified several key strengths, including its scenic route passing near the Botanical Garden, the presence of

agricultural and mountainous landscapes, cultural–religious landmarks such as Imamzadeh sites, and relatively well-planned design in certain segments. However, notable weaknesses were also observed, such as poor asphalt quality in some sections, outdated irrigation practices, insufficient retaining structures, lack of pedestrian infrastructure, visual disorder in certain areas, and noise pollution affecting nearby residents. At the same time, the analysis highlighted important opportunities, including the rehabilitation of degraded lands along the freeway, increasing vegetation cover in the median strip, development of a riverside landscape along the Karaj River, establishment of roadside rest areas, and improvement of visual quality through artistic facade design. Key threats included environmental pollution from heavy traffic, uncontrolled urban development, damage from metro infrastructure, proximity of residential zones to the highway, and weak institutional coordination in landscape management.

Based on these findings, four main design strategies were proposed: enhancing wildlife safety through ecological crossings and protective barriers; improving pedestrian and residential safety via bridges, sidewalks, and bicycle paths; reducing driver fatigue and improving safety through vegetation planning, visual diversity, and rest areas; and restoring ecological continuity by developing linear parks, rehabilitating the Karaj River corridor, and planting native, resilient species to reduce pollution and maintenance needs. Some of these strategies have already progressed to implementation, particularly in the form of linear park and river corridor development projects.

Conclusions

The findings indicate that the Karaj–Qazvin Expressway, despite its important transportation function, faces significant ecological, visual, and safety challenges. Its predominantly traffic-oriented design has disrupted natural habitats, increased risks to wildlife and residents, and created a monotonous and tiring visual experience for drivers. The study therefore emphasizes a shift toward integrated, context-based landscape design that simultaneously addresses human safety, wildlife protection, visual quality, and ecological sustainability. The proposed strategies, including ecological underpasses, pedestrian bridges, protective green walls, linear parks, and roadside rest areas, could transform the expressway into a natural-cultural corridor while improving safety, protecting biodiversity, and enhancing the travel experience. Successful implementation, however, requires institutional coordination, sustainable funding, community participation, and continuous scientific monitoring. Future research should focus on GIS-based mapping of wildlife–vehicle conflict zones, evaluating the effects of interactive landscape elements on driver behavior and public awareness, and quantitatively assessing multilayer vegetation for noise reduction, safety improvement, and ecological sustainability. The proposed approach can also serve as a model for other Iranian freeways facing similar environmental and safety challenges.

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