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The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

The journal is published 4 times a year and contains publications in the following main areas:

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- Automotive Engineering;
- Civil and Structural Engineering;
- Computational Mechanics;
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- Media Technology;
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- Architecture.

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Ecology and roads: environmental impact of road transport and sustainable solutions

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Abstract: Road transportation is one of the most important components of modern infrastructure and economic development. However, the rapid expansion of road networks and the increase in traffic intensity have led to significant environmental challenges. Road transport contributes to air pollution, noise pollution, soil degradation, water contamination, and habitat fragmentation. These environmental impacts affect ecosystems, human health, and the sustainability of urban and rural environments. This study analyzes the ecological impact of road infrastructure and traffic flows on the environment. The research focuses on major environmental indicators such as atmospheric emissions, noise levels, soil contamination, and water pollution near road networks. Statistical analysis, environmental monitoring methods, and traffic flow modeling techniques were used to evaluate the environmental impact of road transportation. The results show that increasing traffic intensity significantly contributes to higher concentrations of harmful emissions such as carbon dioxide (CO_2), nitrogen oxides (NOx), and particulate matter (PM). Furthermore, noise levels in areas adjacent to highways often exceed recommended environmental standards. The study also highlights the importance of sustainable road design, environmental monitoring systems, and green transportation technologies. The findings suggest that integrating ecological considerations into road planning and transportation management can significantly reduce environmental risks and improve sustainability. The implementation of intelligent transportation systems, environmentally friendly materials, and green infrastructure can play a key role in reducing the environmental impact of road transportation.

Keywords: Road ecology, environmental impact, road transportation, air pollution, sustainable transport, environmental monitoring, traffic emissions

1. Introduction

Transportation infrastructure plays a crucial role in economic growth, regional connectivity, and social development. Road networks enable the movement of goods and people, support trade, and facilitate urban expansion. However, the development and operation of road infrastructure also create significant environmental pressures.

According to international environmental studies, the transportation sector accounts for approximately 24% of global carbon dioxide emissions related to energy consumption. The majority of these emissions originate from road vehicles such as passenger cars, trucks, and buses.

The environmental impact of roads can be categorized into several major components:

- air pollution from vehicle emissions
- noise pollution caused by traffic
- soil contamination from heavy metals and oil products
- water pollution from road runoff
- habitat fragmentation and biodiversity loss

These impacts are especially significant in urban areas where traffic density is high and population exposure is greater.

Road construction itself can also cause environmental disturbances. Large-scale infrastructure projects require land clearing, excavation, and alteration of natural landscapes. This can disrupt ecosystems and affect wildlife migration routes [1-11].

In addition, the interaction between transportation systems and environmental processes has become a key topic in modern environmental engineering and sustainable development research.

The concept of **road ecology** has emerged to address these challenges. Road ecology studies the interactions between transportation infrastructure and the natural environment. It aims to reduce environmental damage through improved road design, environmental planning, and sustainable transportation policies [8-15].

2. Research methodology

Road transport is essential for economic and social development, but it has substantial environmental impacts. The construction and use of roads contribute to air pollution through emissions of carbon dioxide, nitrogen oxides, particulate matter, carbon monoxide, and volatile organic compounds, which lead to global warming, smog formation, and respiratory problems. Traffic also produces continuous noise, affecting humans and wildlife, causing stress, sleep disturbances, and altering animal behavior.

Roads disturb water and soil systems, as runoff carries oils, heavy metals, and salts into rivers, lakes, and soils, while construction removes topsoil and disrupts natural drainage. Additionally, roads fragment habitats, restrict wildlife movement, increase collisions with animals, and contribute to biodiversity loss. Road transport is a major source of greenhouse gases, and road construction itself adds to carbon emissions through cement and asphalt production. Modern environmental monitoring uses mathematical

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models and GIS-based analysis to predict pollutant emissions, noise exposure, and ecological risks, helping identify hotspots and vulnerable ecosystems. Sustainable solutions include green infrastructure such as vegetative buffers and wildlife crossings, cleaner vehicles including electric and hybrid transport, promotion of public transport, cycling, and walking, and smart road planning that avoids sensitive areas and reduces habitat fragmentation [2-6]. Additional strategies involve emission and noise reduction technologies, eco-friendly pavements, regulatory measures such as vehicle emission standards, traffic restrictions, and incentives for green transport. Future approaches focus on digital twins, IoT sensors, AI-assisted traffic and pollution management, and the use of sustainable materials to balance mobility with environmental protection. Case studies from regions like Tashkent and Navoiy demonstrate the real-world impact of urban traffic and freight transport on air quality, soil health, and ecosystems, highlighting the need for integrated, data-driven planning for sustainable road networks.

The study uses a combination of statistical analysis, environmental monitoring, and modeling methods to assess the ecological impact of road transportation.

The research methodology includes the following stages:

1. Collection of traffic data
2. Environmental monitoring
3. Emission analysis
4. Statistical modeling
5. Comparative environmental assessment

Traffic Data Collection

Traffic intensity data were collected from urban road networks. The following parameters were analyzed:

- vehicle flow rate (vehicles/hour)
- traffic composition
- average vehicle speed
- peak traffic periods

These parameters are essential for evaluating environmental impacts.

Environmental Monitoring

Environmental indicators were measured near major roads:

- concentration of CO_2
- nitrogen oxides (NOx)
- particulate matter (PM10 and PM2.5)
- noise levels (dB)

Monitoring stations were located at different distances from the road.

Table 1

Environmental Indicators Measured Near Roads

Indicator	Unit	Environmental Impact
CO_2	ppm	greenhouse gas emission
NOx	µg/m³	respiratory diseases
PM2.5	µg/m³	air pollution
Noise	dB	health and stress effects

3. Research Results

Research results from many environmental and transportation studies show that road transport has a measurable and often significant impact on ecological systems, air quality, and human health. Scientific research indicates that road transport contributes a large share of urban air pollution, particularly in rapidly growing cities. Studies conducted by international organizations such as the European Environment Agency and the World Health Organization show that transport activities are responsible for a substantial portion of nitrogen oxide (NOx), particulate matter (PM2.5 and PM10), and carbon dioxide (CO_2) emissions. These pollutants are strongly associated with respiratory diseases, reduced air quality, and climate change. In many metropolitan areas, traffic-related emissions can account for more than one third of total urban air pollution, especially near major highways and intersections.

Recent research emphasizes the importance of sustainable solutions to mitigate these impacts. Field experiments and pilot projects in several countries demonstrate that green infrastructure—such as roadside vegetation barriers, ecological corridors, and permeable pavement—can significantly reduce pollution levels and protect surrounding ecosystems. Environmental monitoring results also show that the introduction of electric vehicles, improved public transportation systems, and intelligent traffic management technologies can lower emissions and improve urban air quality.

Overall, research results consistently indicate that while road transport is essential for economic development and mobility, its environmental consequences are substantial. Modern studies increasingly focus on integrating environmental monitoring, geographic information systems, and advanced data analysis to support sustainable road planning. These approaches help governments and engineers design transportation systems that reduce pollution, protect ecosystems, and maintain a balance between infrastructure development and environmental sustainability.

The results demonstrate that environmental impacts increase significantly with traffic intensity.

Table 2

Traffic Intensity and Emissions

Traffic Intensity (vehicles/hour)	CO_2 emissions (kg/h)	NOx emissions (kg/h)
500	320	12
1000	640	25
2000	1280	50
3000	1950	73

The images below illustrates the level of air pollution on major highways.

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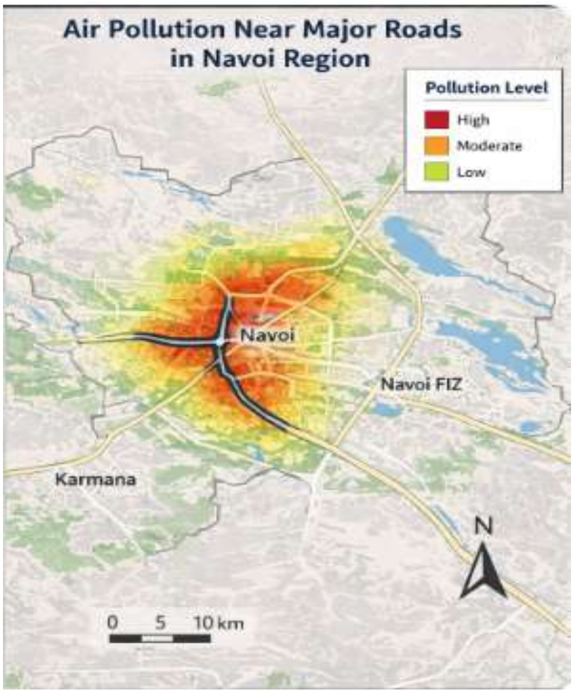

Fig. 1. Air pollution level in Navoiy region

Fig. 2. Air pollution level

The results indicate a strong correlation between traffic intensity and emission levels.

For that the mathematical models were proposed for Traffic emission, Air pollution dispersion and traffic noise which has shown below

Environmental impact assessment of road transportation requires quantitative methods that can evaluate pollution levels, traffic emissions, and ecological risks. Mathematical models are widely used to estimate environmental impacts generated by traffic flows and road infrastructure.

Traffic Emission Model

One of the most commonly used models for estimating emissions from road traffic is based on traffic flow and emission factors.

$$T = \sum_{i=1}^{n}(Q_i \times E \times F_i \times L) \qquad (1)$$

Where:

T – total emissions (kg/h)

Q_i – traffic flow of vehicle type i (vehicles/hour)

$E \times F_i$ – emission factor of vehicle type i (g/km)

L – road segment length (km)

n – number of vehicle categories

This model allows researchers to estimate total emissions produced on a specific road segment.

Air Pollution Dispersion Model

To evaluate how pollutants spread from roads into the surrounding environment, dispersion models are used.

One simplified Gaussian dispersion model can be expressed as:

$$C(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left(-\frac{y^2}{\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right] \qquad (2)$$

Where:

$C(x,y,z)$ – pollutant concentration at point (x,y,z)

Q – emission rate

u – wind speed

σy , σz – dispersion coefficients

H – effective emission height

This model helps determine pollutant concentration at various distances from a road.

Traffic Noise Prediction Model

Traffic noise can be estimated using the following simplified model:

$$\text{Leq} = \omega_1 \frac{C}{C_{max}} + \omega_2 \frac{N}{N_{max}} + \omega_3 \frac{S}{S_{max}} \qquad (3)$$

Where:

Leq – equivalent continuous noise level (dB)

N – number of vehicles of type i

L – noise level generated by vehicle type i

This model allows estimation of average traffic noise levels in urban areas.

Mathematical models are essential tools for understanding and predicting the environmental effects of road transport. They provide a systematic way to estimate pollution, noise, habitat disruption, and ecological risks based on measurable variables such as traffic volume, vehicle type, speed, road design, and surrounding land use. These models help policymakers, engineers, and environmental scientists assess how roads affect air quality, water and soil contamination, and biodiversity before and after construction [4-6].

Models can simulate air pollution dispersion along highways, showing where concentrations of carbon dioxide, nitrogen oxides, or particulate matter are likely to be highest. They can also estimate noise exposure in urban and rural areas, helping to design noise barriers or green buffers effectively. In terms of ecology, models can predict habitat fragmentation and wildlife movement disruptions, which allows planners to identify optimal locations for wildlife crossings or protected corridors.

Mathematical models are often integrated with GIS (Geographic Information Systems) to provide spatial visualization of environmental impacts. This makes it easier to identify hotspots where pollution or ecological risk is highest, and to prioritize interventions. They are also used to test different scenarios, such as the effect of traffic reduction

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measures, electric vehicle adoption, or rerouting roads away from sensitive ecosystems [4-6].

Table 3

Environmental Assessment Table

Indicator	Measured value	Standard limit	Impact level
CO_2 concentration	420 ppm	350 ppm	High
NOx concentration	85 µg/m³	60 µg/m³	Moderate
Noise level	72 dB	55 dB	High
Soil contamination	1.8 mg/kg	1 mg/kg	Moderate

Discussion

The results confirm that road transportation is a significant source of environmental pollution. Rapid urbanization and increasing vehicle ownership have intensified these impacts.

However, several strategies can reduce environmental damage:

Sustainable Road Solutions

1. Development of electric transportation
2. Implementation of intelligent transport systems
3. Use of low-noise pavement materials
4. Installation of green barriers and vegetation
5. Creation of environmental monitoring systems

Green infrastructure plays an important role in reducing pollution levels near roads. Vegetation barriers can absorb pollutants and reduce noise levels.

In addition, digital technologies such as sensors and environmental monitoring systems allow authorities to track environmental conditions in real time.

4. Conclusion

Road infrastructure plays an essential role in economic and social development, but it also creates significant environmental challenges. The study demonstrates that traffic intensity directly influences environmental pollution levels, including air emissions, noise pollution, and soil contamination.

The findings emphasize the importance of integrating environmental considerations into road planning and transportation management. Sustainable transportation policies, advanced monitoring technologies, and environmentally friendly infrastructure solutions can significantly reduce the negative ecological impacts of road networks.

Future research should focus on the development of smart environmental monitoring systems, green transportation technologies, and sustainable urban mobility strategies. By adopting these approaches, it is possible to balance transportation development with environmental protection and ensure long-term sustainability.

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