# ASSESSMENT OF GROUNDWATER MINERALIZATION IMPACT ON SUSTAINABLE ROADSIDE LANDSCAPES IN KARAKALPAKSTAN

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**Abstract.** Groundwater conditions are among the most important environmental and engineering factors affecting the sustainability of roadside landscapes in arid regions. The Republic of Karakalpakstan is characterized by severe climatic conditions, high soil salinity, and intensive desertification processes caused by the Aral Sea crisis. This study evaluates the impact of groundwater mineralization on the sustainability of roadside landscapes in Karakalpakstan. The research analyzes groundwater depth, mineralization levels, and their influence on soil conditions, vegetation development, and road infrastructure. Particular attention is paid to the roadside territories along the A-380 international highway. The study revealed that groundwater mineralization ranging from 3 to 15 g/L significantly affects plant growth, accelerates soil degradation, and reduces the ecological stability of roadside landscapes. Based on the obtained results, innovative landscape solutions including salt-resistant vegetation, drainage systems, and water-saving irrigation technologies are proposed. The implementation of these measures will contribute to the sustainable development of roadside landscapes under arid environmental conditions.

**Keywords:** groundwater mineralization, roadside landscape, Karakalpakstan, sustainability, salinity, A-380 highway, arid regions.

## Introduction

Sustainable development of roadside landscapes is becoming increasingly important in arid regions due to climate change, desertification, and environmental degradation. Groundwater conditions play a crucial role in determining the ecological stability and functionality of roadside ecosystems. High groundwater levels and elevated mineralization negatively influence vegetation growth, soil properties, and the durability of transport infrastructure.

The Republic of Karakalpakstan is located in the northwestern part of Uzbekistan and occupies more than 166 thousand km². The region is characterized by low annual precipitation, high evaporation rates, strong winds, and severe soil salinity. In addition, the desiccation of the Aral Sea has intensified environmental degradation processes throughout the region.

Roadside territories along the A-380 Guzar–Bukhara–Nukus–Beyneu international highway are particularly vulnerable to groundwater-related problems. Therefore, assessing

groundwater mineralization and its influence on roadside landscape sustainability is an important scientific and practical task.

The purpose of this study is to evaluate the impact of groundwater mineralization on sustainable roadside landscapes in Karakalpakstan and to propose innovative measures for improving ecological stability. The scientific novelty of this study lies in assessing the relationship between groundwater mineralization and the sustainability of roadside landscapes under the arid conditions of Karakalpakstan, as well as proposing innovative landscape solutions adapted to saline environments.

**1 Groundwater conditions in Karakalpakstan**

Groundwater conditions in Karakalpakstan vary significantly depending on geographical location and environmental factors. In many districts, groundwater occurs at depths ranging from 1.5 to 3.0 meters. Shallow groundwater levels frequently cause soil salinization and negatively affect plant development.

The average groundwater mineralization in the region varies between 3 and 15 g/L. Higher mineralization levels are commonly observed in areas located near the former Aral Sea shoreline and desertified territories.

Table 1. Groundwater conditions in selected districts

| District | Groundwater depth (m) | Mineralization (g/L) |
|---|---|---|
| Nukus | 2.0 | 4 |
| Khojeli | 1.8 | 6 |
| Kungrad | 1.5 | 10 |
| Moynaq | 1.6 | 12 |
| Beruniy | 2.5 | 5 |

The obtained data indicate that Kungrad and Moynaq districts experience the highest groundwater mineralization levels.

**2 Materials and methods**

The research methodology included field observations, comparative analysis, statistical analysis, hydrogeological assessment, and literature review. Data on groundwater conditions, climatic characteristics, and roadside vegetation were collected from scientific publications, statistical reports, and environmental studies.

The study focused on roadside areas located along the A-380 highway within the Republic of Karakalpakstan. Groundwater depth, mineralization levels, vegetation conditions, and soil characteristics were analyzed. Comparative assessment was used to evaluate the relationship between groundwater mineralization and roadside landscape sustainability.

**3 Impact of groundwater mineralization on roadside landscapes**

Groundwater mineralization has a direct influence on the sustainability of roadside landscapes. Elevated salinity reduces soil fertility, limits water availability for plants, and accelerates vegetation degradation.

Field observations revealed that roadside territories exposed to highly mineralized groundwater demonstrate lower vegetation density and reduced biodiversity. Salt accumulation in root zones decreases plant growth and may lead to the complete destruction of green infrastructure.

Moreover, high groundwater mineralization contributes to roadbed deformation, pavement cracking, and reduced service life of transport infrastructure.

Major environmental impacts include:

- soil salinization;
- degradation of roadside vegetation;
- reduction of biodiversity;
- increased wind erosion;
- deterioration of road embankments.

**4 Assessment of plant sustainability under saline conditions**

Selection of appropriate plant species is essential for sustainable roadside landscaping in Karakalpakstan. Native drought- and salt-resistant species demonstrate better adaptation to harsh environmental conditions.

Table 2. Salt tolerance of selected plant species

| **Plant species** | **Salt tolerance** | **Recommended use** |
|---|---|---|
| Haloxylon aphyllum | High | Protective belts |
| Tamarix spp. | High | Roadside plantations |
| Calligonum spp. | High | Sand stabilization |
| Elaeagnus angustifolia | Medium | Recreational areas |
| Populus euphratica | Medium | Green zones |

Protective green belts established using native species can reduce wind speed by up to 30% and significantly improve microclimatic conditions.

To improve roadside landscape sustainability under saline conditions, several innovative measures are recommended:

- establishment of multi-row protective green belts;
- application of drought- and salt-resistant native plant species;
- installation of drip irrigation systems;
- construction of drainage networks;
- use of geosynthetic materials for soil stabilization;
- implementation of solar-powered irrigation and lighting systems;
- development of modular roadside rest areas.

These solutions will contribute to environmental restoration and enhance the visual quality of roadside territories.

**Conclusion**

The study demonstrated that groundwater mineralization is one of the key factors affecting the sustainability of roadside landscapes in Karakalpakstan. High salinity levels negatively influence vegetation growth, soil properties, and transport infrastructure.

The results indicate that sustainable roadside landscaping in arid regions requires an integrated approach combining hydrogeological assessment, appropriate plant selection, efficient irrigation technologies, and protective green infrastructure. The proposed innovative landscape solutions can significantly improve ecological stability, road safety, and the aesthetic quality of roadside areas in Karakalpakstan.

The proposed recommendations can be applied during the planning, reconstruction, and maintenance of roadside landscapes along international highways in arid regions of Uzbekistan.

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