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The Significance of Measures for the Protection of Mountain and Foothill Roads from Tectonic Movements, Washing, and Erosion

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Abstract: This article examines the significance of protective measures for highways located in mountainous and foothill regions against the impacts of tectonic movements, soil erosion, washing, and related natural processes. The study highlights that intensive precipitation, surface runoff, wind activity, landslides, and geological deformations significantly deteriorate road stability and reduce transportation safety. The research analyzes different types of erosion processes, including water, wind, and irrigation erosion, and their influence on roadbed degradation. Special attention is given to engineering and agrotechnical solutions such as drainage systems, slope reinforcement, geosynthetic materials, and vegetation cover. The findings indicate that integrated protection strategies substantially reduce soil loss, prevent road deformation, and improve long-term durability of road infrastructure. The study concludes that sustainable road management in complex mountainous conditions requires a combination of hydraulic, geotechnical, and ecological approaches to minimize the adverse effects of natural and anthropogenic factors and ensure safe transportation networks across regions worldwide.

Keywords: mountain roads, soil erosion, landslides, subsidence, displacement, climate, erosion, wind, water, tectonic movements.

Introduction

Protecting highways located in mountainous and foothill areas from the influence of natural and climatic factors is one of the most important and urgent issues today. In particular, as a result of heavy precipitation, mudflows, snow and ice melting, wind action, and tectonic movements, various deformations occur on the roadbed and road structures. Such processes lead to the erosion of the road surface, the collapse of slopes, the erosion of the soil layer, and a decrease in traffic safety. Therefore, ensuring the stability of highways in mountainous areas and protecting them from erosion and weathering is of great scientific and practical importance. Soil erosion is the process of soil layer erosion and movement from one place to another under the influence of natural factors. This process occurs mainly under the influence of water and wind. The erosion of soil under the influence of water currents is called water erosion. The movement of soil particles under the influence of wind is called wind erosion or deflation. This process is primarily observed in dry and sparsely vegetated areas. Strong winds blow away small particles of soil, causing the earth's surface to erode. As a result, negative situations arise in the areas around the road, such as sand cover, pollution of the road surface, and reduced visibility. Erosion processes intensify in mountainous and foothill areas, significantly impacting the technical condition of highways. Therefore, during the design, construction, and operation of roads, it is important to implement anti-erosion protection measures, including the construction of drainage systems, slope reinforcement, the use of geosynthetic materials, and landscaping.

Main part

Water erosion is also divided into two types: mass erosion, or surface erosion, and longitudinal erosion, or cliff erosion. Also, depending on the influence of running water, water erosion is divided into erosion caused by surface runoff (snow and rainwater) and irrigation erosion caused by irrigation water. Mass erosion (surface erosion) is more common. The upper horizons of the soil are eroded by water flowing along the slopes. Under the influence of running water, the soil thickness decreases, and along with particles of various sizes in the fertile part of the soil, nutrients are washed away and deposited on low-slope and flat areas. In eroded areas, crop yields decrease sharply, while on eroded deposits, the plant grows stunted, the crop does not ripen, and the yield is relatively low.[1]

Metodology

This study employs a comprehensive methodological approach to investigate the protection of mountain and foothill highways from tectonic movements, water and wind erosion, washing processes, and landslides. First, a detailed literature review was conducted, analyzing scientific publications, technical reports, and engineering standards related to road stability and erosion mechanisms. This allowed the identification of key factors influencing road degradation in complex terrain. In addition, an analytical method was used to classify erosion processes and their impacts on road infrastructure performance under different climatic and geological conditions.

Furthermore, field observation methods were applied to assess the physical condition of road sections, slopes, and drainage systems in mountainous areas. Comparative analysis was then conducted between protected and unprotected sites to evaluate the effectiveness of engineering measures. Hydrological and geotechnical assessments, supported by GIS mapping techniques, were used to determine runoff intensity, soil stability, and erosion risk zones, ensuring reliable results for validation.

Results and Discussion

Longitudinal or cliff erosion is the deepening and erosion of soil under the influence of strong water currents coming from the slopes. This process occurs in several stages: initially, small depressions (20–25 cm) are formed, and as they expand, depressions ranging from 0.3–0.5 to 1–1.5 m are formed. Geological erosion is a process of gradual leaching of particles from the soil surface covered by vegetation, during which the soil layers washed away during soil formation are restored. Accelerated erosion is associated with the active activity of humans and occurs when vegetation on the soil surface is destroyed and land is used incorrectly (anthropogenic erosion). In this case, the intensity of erosion increases sharply, and the lost soil layers are not restored.[2]

Figure 1. Water erosion and soil erosion

In the conditions of irrigated agriculture in Central Asia, irrigation soil erosion is widespread and is a form of water erosion. As a result of the development of lands with high slopes and their use in cotton growing, the area of such erosion has increased in recent years. For example, in the irrigated regions of Uzbekistan, the area of irrigation erosion was 695.1 thousand hectares in 1990, and by 2012, it amounted to approximately 1,051.9 thousand hectares.[3,4,5]

According to data from Uzbek soil scientists, during a single furrow irrigation on slopes, water runoff reaches 22–50 tons per hectare, and on very steep slopes, it reaches 690 tons. For example, it has been established that 94 percent of wastewater on slopes of 3-50 meters is soil, while only 6 percent is sand.[6,7]

The annual erosion of an average of 100 t of soil per hectare means the loss of 100 kg of nitrogen and 115 kg of phosphorus.[8]

In areas with high slopes, when water flows into the field with a high flow, its flow velocity reaches a critical value and begins to erode the furrow.

Figure 2. Slopes reinforcement and hydro-technical measures

The critical velocity depends on the soil's erosion resistance, mechanical composition, granularity, and other properties.[9,10]

As a result of irrigation erosion, the water-physical, agrochemical, and microbiological properties of the soil deteriorate sharply, fertility decreases, cotton yield decreases by 30-40% or more, fiber quality decreases, and seed germination occurs slowly.[11,12,13,14]

When the arable layer of the soil is washed away, in addition to the erosion of the nutrient layer, the physical properties of the soil deteriorate sharply. When the humus horizon is washed away, a low-productivity dense subsoil layer emerges to the surface. Conditions necessary for the life of plants and the activity of microorganisms on these lands deteriorate; secondly, due to the difficulty of water absorption, soil erosion intensifies.[15,16,17]

In spring, as a result of high surface water runoff (up to 60-80%) and poor water permeability, active moisture reserves accumulate less in eroded soils.

In agriculture, ravine erosion also causes immense damage. In our country, the area occupied by ravines is very large (more than 5.0 million hectares). To visualize the damage caused by a volcanic event, it is sufficient to cite the following figure: 650 tons of soil will be carried away when a depression (pit) fifty meters long, four meters deep, and two and a half meters wide is formed. Furthermore, a significant amount of nutrients is lost. To compensate for this, it is necessary to provide 20 lb. of manure and 3-4 lb. of various mineral fertilizers[18,19,20].

Wind erosion also causes great damage to agriculture. Wind erosion also causes great damage to agriculture.

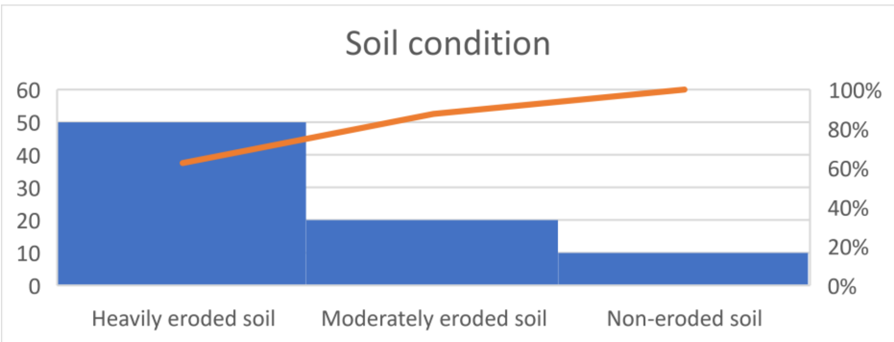

Figure 3. Fertilizer increase (%)

Even when a 2.5 cm layer of soil is blown away by wind, 450-1000 kg of nitrogen, 100-200 kg of phosphorus, up to 3.5 tG of potassium, and up to 15 tons of humus are lost from each hectare. In addition, hot hot winds and dust storms have a negative impact on crop yields. It takes many years to restore the soil layer lost due to wind erosion. In Uzbekistan, wind erosion covers 37.3 million hectares, including more than 2 million hectares of arable land.

Conclusion

Organizational and economic measures are aimed at drawing up justified plans for erosion control and their practical implementation. An important role in this is played by the compilation of materials such as soil maps and cartograms reflecting the degree of erosion of individual areas. Based on these materials, the direction and specialization of farms are determined, and specific plans for erosion control in specific territories are drawn up.

Agrotechnical measures include the use of perennial grasses and annual crops to protect soils from erosion, the application of optimal tillage methods, the use of special measures for snow accumulation and regulation of snow runoff, as well as the use of agrochemical means to increase soil fertility.

As the degree of soil erosion increases, its demand for fertilizers increases. As a result, the effectiveness of the applied fertilizers will be high. Therefore, the fertilizer rate is increased by 20% on moderately eroded soils and by 50% on heavily eroded areas compared to non-eroded soils.

When sufficient moisture accumulates in the soil, fertilizers yield a good effect, nutrient runoff with water decreases, and water bodies are less polluted.

Strict adherence to irrigation techniques is necessary to prevent irrigation erosion.

To this end, it is recommended to implement the following measures.

At a field slope of 2–30° and a furrow length of 50 m, the water flow rate in each furrow at the beginning of irrigation is 0.07 liters per second, and after the furrow edges are moistened, the flow rate can be increased to 0.1 liters per second.

For slopes of 3–4° and furrow lengths up to 100 m, it should be 0.15–0.10 liters per second, and for slopes of 4–60°, it should be 0.10–0.05 liters per second. In very sloping cotton fields, it is necessary to change the water flow and widely apply irrigation without draining water from the collector.

It is necessary to level the irrigated fields in such a way that it is possible to select optimal elements of irrigation technology and achieve uniform moistening of the cotton field and economical water consumption;

Widespread use of flexible and semi-flexible hoses for irrigating cotton and other agricultural crops, allowing for the regulation of water flow to each furrow;

It is important to use other effective erosion control measures that significantly reduce the damage caused by erosion. A comprehensive method of forest reclamation and hydraulic engineering measures is effective in preventing and combating erosion.

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