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FEATURES OF THE DEVELOPMENT OF GEOMORPHOLOGICAL PROCESSES (CREEP AND EROSION) IN MOUNTAIN AREAS: EVIDENCE FROM UZBEKISTAN

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Abstract: Mountain environments in Uzbekistan are characterized by high relief energy, active neotectonics, and sharp hydro-climatic gradients, which together create favorable conditions for slope deformation and accelerated denudation. This article synthesizes the spatial patterns and controlling natural factors of two key geomorphological processes—creep (including slow landslides and periglacial solifluction) and erosion (sheet, rill, gully, and channel erosion)—using evidence from published case studies and recent remote-sensing applications in the Western Tien Shan and Pamir–Alay sectors. A conceptual framework is proposed in which (I) lithology and weathering state set the threshold strength of hillslopes, (II) topography and structural discontinuities regulate stress and drainage pathways, and (III) hydro-meteorological forcing (rainfall intensity, snowmelt timing, and groundwater response) triggers seasonal acceleration and episodic failures. The review highlights that most hazardous slope events cluster in foothill–mid-mountain belts where loess and colluvial covers overlie weaker bedrock and where anthropogenic disturbances (road cuts, irrigation seepage, reservoir water-level fluctuations) amplify natural susceptibility.

Keywords: creep; slow landslides; solifluction; soil erosion; gully erosion; Western Tien Shan; Pamir–Alay; Uzbekistan

Introduction

Geomorphological processes in mountain areas shape landscapes, regulate sediment delivery to rivers, and—when accelerated—become a source of natural hazards. In Uzbekistan, mountainous and foothill territories host dense transport corridors, hydropower and water-supply infrastructure, and rapidly growing tourist zones, while also containing some of the country's most active exogenous geological processes (landslides, debris flows, rockfalls, and erosion). Among these, creep and erosion represent two ends of a continuum: creep expresses sustained, often seasonal, deformation of hillslopes, whereas erosion expresses net removal and redistribution of material by water, gravity, and wind. They are tightly coupled: creep supplies mobile colluvium and weakens slope structure, and erosion undercuts toes and concentrates runoff, promoting further deformation.

This paper focuses on the 'features of development' of creep and erosion in Uzbekistan's mountain areas—i.e., where and why these processes concentrate, how they evolve in time, and which natural factors dominate the process hierarchy. While the article is written as a synthesis, it is anchored to the best-documented Uzbek examples in the Western Tien Shan (e.g., the Bostanlik–Charvak sector) and in major foothill belts influenced by loess and seismicity. The objective is to provide a publication-ready, practice-oriented narrative suitable for multidisciplinary audiences (geomorphology, hazards, water resources, land management).

Uzbekistan's mountainous terrain forms part of two major orogenic systems: the Western Tien Shan in the east and northeast, and the Pamir–Alay system in the south. Key ranges and massifs include the Chatkal–Kurama and Ugam–Pskem sectors of the Western Tien Shan, and the Hissar–Alay ranges of the Pamir–Alay. Relief energy increases sharply from the intermontane basins and piedmont plains to high crests, producing steep valley-side slopes and narrow gorges. Hydro-climatic gradients are similarly strong: precipitation generally increases with elevation, and the seasonal transition from snow accumulation to snowmelt creates

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pronounced spring runoff peaks that can synchronize triggering of slope instabilities and erosion pulses.

A distinctive characteristic of many Uzbek mountain and foothill slopes is the presence of thick unconsolidated covers—loess, loess-like loams, and colluvium—resting on bedrock of variable strength. These covers are sensitive to wetting and exhibit low shear strength when saturated, especially where layered structures, paleosols, or clay interbeds create perched water tables. In addition, Uzbekistan is located in an active intracontinental deformation zone; earthquakes and associated ground shaking act as an important preparatory and triggering factor for mass movements and for slope-material remobilization.

Materials and Methods

The article uses a structured synthesis approach combining: (i) peer-reviewed and grey literature on landslides, slope processes, erosion and monitoring in Uzbekistan; (ii) examples of modern geospatial workflows applied in Uzbek mountain catchments (multi-criteria hazard assessment, object-based landslide inventory, and satellite InSAR monitoring); and (iii) geomorphological process reasoning that links observed spatial patterns to controlling natural factors. In practice-oriented terms, the methods discussed below represent an ‘integrated toolkit’ that can be applied in Uzbek mountain districts.

Topographic controls are assessed using digital elevation models (DEMs) to derive slope gradient, curvature, contributing area, and topographic wetness indices. Erosion risk is typically evaluated with coupled terrain–climate–cover metrics, including rainfall erosivity and vegetation indices, and (where data allow) empirical models such as RUSLE as a first-order spatial screening. Creep and slow landslides are diagnosed via field indicators (terracettes, tilted trunks, tension cracks, sag ponds) and remotely via time-series deformation analysis using Sentinel-1 InSAR, supported by inventories that delineate landslide bodies and source zones. For complex sites (reservoir margins, road corridors), multi-criteria decision analysis (e.g., Analytic Hierarchy Process, AHP) can integrate multiple susceptibility indicators into a single geohazard index.

Results and Discussion

Spatial pattern of erosion in Uzbek mountain catchments. Erosion intensity in mountains is primarily organized by energy gradients and runoff concentration. In Uzbekistan, the most erosion-prone zones typically occur in mid-altitude belts where slopes are steep enough for rapid overland flow but where vegetation cover is seasonally reduced by grazing, cultivation, or drought. Foothill loess slopes are especially susceptible to rill and gully initiation because loess is highly erodible, forms surface crusts that increase runoff, and often contains shrink–swell or dispersive horizons that promote incision.

Recent basin-scale studies illustrate that erosion forcing has strengthened in parts of eastern Uzbekistan. For example, an assessment of rainfall-runoff erosivity for the Chirchik–Akhangaran basin reports an increasing trend in annual erosivity and links this to changes in the frequency and intensity of precipitation, which has direct implications for slopewash and gully growth in tributary mountain catchments. Such trends imply that even without major land-use changes, the climatic component of erosion hazard may increase, raising sediment yield and reservoir siltation risks.

Creep in mountain geomorphology includes several process families: (a) soil creep driven by cyclic wetting–drying, freeze–thaw, and bioturbation; (b) solifluction/gelifluction—slow, seasonal flow of water-saturated regolith in periglacial belts; and (c) deep-seated gravitational slope deformation and slow landslides where movement occurs along shear zones or weak stratigraphic horizons. In Uzbekistan, field evidence of creep is most commonly reported in loess and colluvial mantles of the foothill–mid-mountain zone, where spring snowmelt and episodic rainfall drive pore-pressure increases. Terracettes, bent trunks, and shallow tension cracks are

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common indicators, while toe bulging and road-surface deformation reveal deeper or more persistent movement.

Quantitative studies indicate that hazardous slope processes are widespread in the country's eastern mountainous provinces. A synthesis focusing on Tashkent Province reports more than 630 identified dangerous landslides and emphasizes the role of hydro-meteorological forcing (rainfall and snowmelt) alongside seismic and technogenic factors, underscoring that creep-like, slowly accelerating movements often precede rapid failures. From a monitoring perspective, this makes creep a critical 'early stage' process: detecting acceleration phases enables timely risk reduction.

Periglacial creep (solifluction) at high elevations. Although Uzbekistan's highest elevations are limited compared to the central Tien Shan, periglacial processes still operate in the high mountain belts of the broader region and are relevant to Uzbek sectors of the Western Tien Shan and Pamir–Alay. Solifluction represents a seasonal creep process that becomes effective where the active layer thaws over frozen ground and water-saturated regolith deforms downslope. A classic regional study of Central Asia reports that the solifluction belt in the Tien Shan and Pamir–Alay spans roughly 900–1400 m in vertical extent, with the lower limit rising from about 2500 m in the northern ranges to about 3800 m in the southern sector—highlighting strong climatic control. In Uzbekistan, the implication is that periglacial creep may be locally important near the highest ridgelines and shaded hollows, where it contributes to fine material supply and to the slow deformation of debris mantles.

Reservoir margins, tectonics, and human disturbance as 'process accelerators' Uzbek mountain geomorphological processes are increasingly influenced by large infrastructure and land-use pressures. Reservoir shorelines, in particular, combine steep topography with water-level fluctuations that alter pore pressures and effective stress in bank materials. In the Charvak reservoir basin, multi-criteria geohazard mapping based on remote sensing and GIS has been used to integrate key susceptibility indicators (slope gradient, lithological strength, lineament density, wetness indices, distance to active faults, and distance to the shoreline) into a composite hazard index. Such results support a central conclusion: in tectonically structured mountain basins, slope gradient and structural discontinuities (faults/lineaments) often act as dominant predisposing factors, while hydrological forcing controls short-term activation.

Mining and road construction can generate similar acceleration effects by (i) steepening slopes via cuts, (ii) changing drainage pathways, and (iii) introducing vibrations. These disturbances can convert background creep into damaging slow landslides or can trigger rapid failures after rainfall or earthquakes. Because of this, Uzbekistan has established dedicated institutional monitoring of hazardous geological processes, and the legal basis for a State Monitoring Service was set as early as 1994. Recent hazard-risk projects have also introduced in-situ displacement monitoring devices in high-risk mountain sectors, illustrating the movement from mapping toward operational early warning.

Coupling between creep and erosion: a hillslope–channel feedback perspective. Creep and erosion interact through sediment supply, drainage reorganization, and threshold behavior. Where creep thickens colluvium and forms micro-terraces, infiltration can increase locally, but once runoff exceeds infiltration capacity, rills and gullies preferentially incise along tension cracks and depressions created by deformation. Conversely, gully headcut retreat and channel incision undercut slope toes, steepen local gradients, and raise shear stress, favoring renewed creep and landslide reactivation. This coupling is especially important for mountain basins where reservoirs and downstream irrigation systems depend on stable sediment regimes.

Lithology and regolith properties. Lithology controls geomorphological process development by setting material strength, permeability structure, and weathering pathways. In

Uzbek mountain and foothill zones, the most problematic combinations include loess-like covers overlying low-strength sedimentary rocks, and fractured metamorphic or volcanic rocks with clay-rich alteration zones. Layered stratigraphy can produce perched water tables, creating seasonal pore-pressure peaks that amplify both creep and rill/gully erosion.

Topography and structural discontinuities. Topography regulates gravitational driving stress and runoff routing. Steeper slopes are more prone to both creep acceleration and erosional detachment, while convergent hollows and concave planforms concentrate subsurface flow and favor translational sliding. At the landscape scale, faults and lineaments guide valley orientation and can localize weakened rock masses, explaining why lineament density and proximity to active faults often rank highly in susceptibility models for Uzbek mountain basins.

Hydro-climatic forcing and seasonality. Hydro-climatic forcing is the dominant short-term trigger for many slope processes. In Uzbekistan, the seasonal co-occurrence of snowmelt, spring rainfall, and rapid groundwater response produces a 'critical window' for creep acceleration, landslide initiation, and debris-flow generation. Rainfall erosivity is a key driver of soil erosion; increasing intensity and frequency of high-rainfall days can substantially increase erosive power even if annual totals change modestly.

Seismicity as a preparatory and triggering factor. Seismicity acts both as a trigger and as a preparatory factor: shaking can directly initiate failures, but it also fractures rock masses, degrades soil structure, and increases the long-term probability of deformation under later hydrological loading. Earthquake-triggered landslides and secondary mudflows are therefore an important component of multi-hazard risk in Uzbek mountain territories.

Monitoring and Management Implications. For creep, the priority is to identify actively deforming slopes before catastrophic acceleration. A modern monitoring chain can combine: (I) an EO-based landslide inventory updated annually; (II) Sentinel-1 InSAR screening to detect millimeter–centimeter scale deformation hotspots; and (III) targeted in-situ monitoring (extensometers, inclinometers, piezometers) in critical corridors and near reservoirs. For erosion, risk reduction is primarily land-management oriented: maintaining vegetative cover, controlling grazing pressure, contour farming/terracing on cultivated slopes, and stabilizing gully heads and drainage lines with bioengineering and check dams. Because creep and erosion are coupled, measures that reduce runoff concentration and maintain soil structure also reduce the likelihood of landslide reactivation.

Institutionally, effective practice requires linking monitoring outputs to decision thresholds—e.g., rainfall and snowmelt indices that trigger inspections and temporary road closures, and deformation-rate thresholds that prompt engineering mitigation. Uzbekistan's existing State Monitoring Service and recent international projects installing monitoring devices in mountain sectors offer a foundation for scaling such systems nationwide.

Conclusion

Creep and erosion in Uzbekistan's mountain areas display clear spatial organization controlled by (I) regolith–lithology contrasts (especially loess and colluvial covers), (II) steep, structurally guided topography, and (III) strong seasonal hydro-climatic forcing. Foothill to mid-mountain belts—where human disturbance is high and where wetting-driven strength loss is common—represent the most critical zones for combined creep–erosion hazards. Recent advances in geospatial hazard assessment and satellite monitoring demonstrate that Uzbekistan can move beyond static susceptibility maps toward dynamic, operational early warning, particularly around reservoirs and transport corridors. Future research should prioritize integrated hillslope–catchment sediment budgets, long-term deformation time series, and process-based thresholds that translate into actionable risk management.

Table 1.

Process–factor relationships and recommended monitoring approaches for Uzbek mountain areas

Process	Typical settings in Uzbekistan	Dominant natural controls	Key field/RS indicators	Monitoring & mitigation priorities
Soil creep	Loess/colluvium on foothill–mid-mountain slopes; valley-side hollows	Seasonal wetting–drying; snowmelt; weak horizons; slope gradient	Terracettes; tilted trees; tension cracks; small scarps	InSAR screening; field benchmarks; drainage control; toe protection
Slow landslides (creeping)	Structurally controlled slopes; road cuts; reservoir margins	Lithological contrast; faults/lineaments groundwater response; seismic preconditioning	Persistent cracks; bulging toes; road deformation displaced blocks	In-situ extensometers/piezometers; slope stabilization; regulated water levels
Solifluction (periglacial creep)	Highest elevation belts and shaded hollows (regional context)	Freeze–thaw; active-layer saturation; permafrost/seasonal frost	Lobes; sheets; sorted stripes; saturated turf	Seasonal surveys; climate monitoring; avoid siting infrastructure on lobes
Sheet/rill erosion	Steep cultivated/grazed slopes with sparse cover	Rainfall erosivity; soil texture; slope length; vegetation cover	Bare patches; rills; sediment fans; NDVI decline	Cover management; contour farming; terracing; mulching
Gully erosion	Concentrated runoff lines; loess slopes; lineament-guided drainage	Runoff concentration; dispersive soils; headcut dynamics; extreme rain	Headcuts; widening channels; bank failures; high sediment yield	Gully-head stabilization; check dams; land-use zoning

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