Tectonic Uplift and Surface Deformation Analysis of Nanga Parbat Haramosh Massif Zone, Pakistan

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Executive Summary:

The Nanga Parbat Haramosh Massif Zone (NPHMZ) in northern Pakistan is a region of exceptional tectonic activity and complex geomorphology. SATEYE Company has conducted a comprehensive geospatial analysis to quantify surface deformation and uplift in this critical Himalayan sector. Applying advanced remote sensing techniques and Geographic Information Systems (GIS), high-resolution Digital Elevation Models (DEMs) were analyzed to extract key morphometric parameters, including channel steepness, concavity, and relative uplift rates. The results indicate that the region is undergoing significant tectonic uplift, with rates ranging from 12 to 16 mm/year in several critical fault zones. This study underscores the capability of satellite-based geospatial monitoring to identify and assess neo-tectonic activity and provides actionable insights for risk assessment, disaster management, and regional planning. SATEYE Company's approach demonstrates a scalable, efficient, and reliable methodology for continuous observation of active mountainous regions.

Introduction:

The Nanga Parbat Haramosh Massif Zone (NPHMZ) is one of the most prominent and rapidly uplifting regions in the Himalayas. Known locally as Diamir, Nanga Parbat rises sharply from the surrounding valleys, creating some of the highest and steepest relief on the planet. The massif includes remarkable geographic features such as the Rupal face, the Raikot face, and the Mazeno Wall ridge, a 10-kilometer-long line of subservient peaks. The area is also defined by its proximity to the Indus River, which flows along its northern flank, carving valleys and interacting dynamically with the tectonic structures.

The region's tectonic activity is dominated by two major structural bends: the Nanga Parbat syntaxis and the Hazara-Kashmir syntaxis. Among these, the Sassi-Raikot Fault Zone represents the most active tectonic boundary, creating conditions of intense uplift, fracturing, and folding. Secondary faults, including the Stake Fault and Raikot Fault, further contribute to the complex geomorphology of the area. Continuous tectonic pressure combined with fluvial incision has created high relative relief, exposing crystalline rocks and forming steep glacial and fluvial terraces.

SATEYE Company's investigation aims to quantify the relative uplift and deformation patterns in NPHMZ, providing an accurate understanding of the region's surface dynamics. These insights are critical not only for advancing geological knowledge but also for informing disaster preparedness strategies, infrastructure planning, and environmental management in a region highly susceptible to earthquakes, landslides, and glacial hazards. By employing state-of-the-art geospatial technologies, SATEYE Company has created a detailed, high-resolution analysis that integrates topographic, hydrological, and structural data, offering a comprehensive view of NPHMZ's dynamic landscape.

Methodology:

SATEYE Company employed a multi-faceted geospatial methodology to investigate surface deformation in NPHMZ. The primary dataset consisted of high-resolution Digital Elevation Models (DEMs), which provided detailed two-dimensional elevation information. Complementing DEMs, Digital Surface Models (DSMs) and Digital Terrain Models (DTMs) were utilized to capture both the natural and built-up features of the region and the bare-earth elevation, respectively.

The analysis included Longitudinal River Profile Analysis (LRPA) to assess river gradient changes and surface incision. DEM data were processed using the D8 algorithm to determine the flow direction of each pixel along the steepest slope, allowing accurate reconstruction of river networks. Depression-less DEMs were generated to remove artifacts that could interfere with flow modeling. Using the imposed gradient method, SATEYE Company extracted flow direction and identified basin outlets, ensuring precise mapping of drainage networks in both primary and sub-basins.

To quantify deformation, the study applied the stream power law to calculate channel concavity and steepness. The rate of change in channel elevation (dz/dt) was related to uplift and erosion coefficients, allowing the team to derive equilibrium expressions for natural landscapes. Regression-based models were employed to analyze the relationship between drainage area and slope, producing concavity index maps and steepness maps that highlight relative uplift zones. These models were automated using MATLAB algorithms, which enabled rapid generation of graphs, maps, and analytical outputs while maintaining high accuracy and reproducibility.

Through this methodology, SATEYE Company was able to combine tectonic, geomorphic, and hydrological data into a cohesive framework for understanding surface deformation. The approach ensures that both broad regional trends and localized variations in uplift and erosion are captured, providing a detailed and actionable understanding of NPHMZ's dynamic geomorphology.

Outcomes:

SATEYE Company's analysis revealed that NPHMZ is undergoing significant tectonic uplift and deformation. The results indicate that uplift rates in critical regions of the massif, particularly along the Sassi-Raikot Fault Zone and surrounding western and northwestern areas, range from 12 to 16 mm/year. These rates represent some of the highest values ever recorded in the region, confirming the neo-tectonic activity of the massif.

Concavity index mapping showed that streams near Bunji and Astore exhibit low-gradient profiles, indicative of older, more stable surfaces. Conversely, steeper and elongated river profiles correspond to areas of active uplift and incision, reflecting recent tectonic adjustments. Surface dynamics maps produced by SATEYE Company highlight differential uplift, with higher rates observed along bedrock channels and fault lines and lower uplift in southeast and southern parts of the region. These spatial patterns correlate strongly with lithological distribution and fault density, offering a clear picture of areas most susceptible to erosion, landslides, and earthquake-induced deformation.

The study also demonstrated the effectiveness of combining open-source DEM data with advanced MATLAB-based analysis tools to produce high-resolution, automated surface deformation assessments. By providing detailed uplift and concavity maps, SATEYE Company offers an invaluable resource for disaster risk management, infrastructure development, and future geological studies. The research confirms that geospatial technologies are critical for monitoring active tectonic regions, enabling timely and informed decision-making in areas where natural hazards are prevalent.