Hydrological Erosion Dynamics in Semi-Arid Mountain Watersheds of the High Atlas (Marrakech, Morocco): A PAP/CAR-Based Assessment

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ABSTRACT

Water erosion represents one of the most critical hydrological processes affecting semi-arid mountain river systems, where torrential rainfall, steep topography, sensitive lithology, and growing anthropogenic pressures — including overgrazing, deforestation, and agricultural expansion — generate intense sediment production and transfer toward downstream river networks. In the High Atlas watersheds of Marrakech (Morocco), these dynamics are particularly pronounced, making this region a representative case study for African mountain basins facing accelerated degradation and increasing hydrological hazards.

This study applies the three complementary approaches of the PAP/CAR guidelines (1998) — predictive, descriptive, and integrative — within a geomatics environment combining Geographic Information System (GIS), multitemporal Sentinel-2 satellite imagery, and a Digital Elevation Model (DEM). The predictive approach mapped intrinsic erosion susceptibility by integrating topographic variables, lithological data, and vegetation indices (NDVI). The descriptive approach identified active erosion forms through field surveys and remote sensing interpretation. The integrative approach produced a hierarchical map of erosion states and evolutionary trends, serving as the primary decision-support tool for watershed management.

Results show that more than 67% of the total watershed area exhibits high to very high erosion sensitivity. Sheet erosion constitutes the dominant process, while deep gullies and badlands reflect advanced degradation states with significant contributions to river sediment loads. Approximately 15.6% of the territory is in an active intensification phase and 3% displays near-irreversible degradation.

These findings confirm the determining role of lithology and land use on the spatial distribution of erosion, consistent with documented patterns in Moroccan and African catchments. This study demonstrates that integrating PAP/CAR guidelines with modern geomatics tools provides a robust and operational framework for diagnosing erosion-driven sediment dynamics and guiding differentiated watershed conservation strategies in semi-arid African mountain environments facing increasing climate and anthropogenic pressures.

Keywords: Water erosion; PAP/CAR; Semi-arid watershed; High Atlas