Linking frequency of rainstorms, runoff generation and sediment transport across hyperarid talus-pediment slopes

Yuval Shmilovitz¹, Efrat Morin¹, Yair Rinat¹, Itai Havi², Genadi Carmi³, Amit Mushkin⁴, and Yehouda Enzel¹

¹The Fredy & Nadine Herrmann Institute of Earth Sciences, The Hebrew University of Jerusalem, Jerusalem, Israel
²Department of Geological and Environmental Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel
³Wyler Department of Dryland Agriculture, Ben-Gurion University of the Negev, Sede Boqer Campus, Israel
⁴Geological Survey of Israel

Talus-pediment slopes are a common morphologic feature in arid areas and constitute a prominent runoff and sediment source at the watershed and channel scales. The evolution of talus-pediment sequences (talus flatirons) was often linked to climatic cycles, although the physical processes that may account for such a link remained obscure. Our approach is to integrate field measurements, high-resolution radar rainfall data and numerical modeling to link the frequency of storms and the resulted hillslope runoff and sediment transport. We present a quantitative hydrometeorological analysis of rainstorms and their geomorphic impact, potentially involved in the evolution of arid talus-pediment slopes in the Negev desert (Israel). Artificial rainstorms were designed based on intensity-duration-frequency curves and simulated in the field using a rainfall simulator. Then, the obtained experimental results were up-scaled to the entire slope length using a fully distributed hydrological model. In addition, natural storms and their hydro-geomorphic impacts were monitored using X-band radar and time-lapse cameras.

These integrated analyses constrain the rainfall threshold for local runoff generation at rain intensity of 14-22 mm h⁻¹ for a duration of 5 min for the study area conditions. We characterized small-scale runoff-generating convective rain cells using an X-band radar and found that small convective cells (~30 km²), having extremely high internal spatial gradients in rainfall intensity and low velocity (<10 m s⁻¹), have the potential to generate local hillslope runoff. The frequency of local runoff-producing rainstorms is ~1-3 per year, but most of these storms activate only small parts of the hillslope. Modeling results indicate that a full extent hillslope runoff occurs under much rarer rainstorms of at least 100-years return interval (1% or less). During such rainstorms, the shear stress produced by the runoff flow (sheetwash) is capable of transporting surface clasts at a distance of ~80 m downslope. However, transport of coarse clasts in the upper parts of the slopes is most probably gravitationally controlled. The erosion efficiency of discrete rare events (1% or less) on the lower part of the slopes highlights their potential to trigger incision and lead to cliff dissection. This study results support the hypothesis that a climatic shift in terms of the properties and frequency of extreme rainstorms, rather than the common views of it as changing precipitation means, can play an important role in shaping and in transforming landscapes in such
arid setting.