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Impacts of Overgrazing on Hydrological, Soil, and Vegetation Responses in the Alamedin and Ala Archa Watersheds.

Introduction

Climate change results in serious impacts, including rising temperatures in mountainous regions, shrinking glaciers, and altered precipitation patterns, which when coupled with human disturbances, like overgrazing, can further modify local environmental conditions (Crozier, 2010; Pepin et al., 2015; Hock & Huss, 2021). In Central Asia, melting glaciers and altered snowmelt patterns are reshaping river flows and flooding mountain lakes, as seen in the Tien-Shan mountains of Kyrgyzstan (Jansky et al., 2009; Meiners, 1997), accelerating the risk of natural disasters such as flooding and landslides. Widespread overgrazing, compounded by the impacts of climate change, further threatens both ecosystem stability and local livelihoods (Ludi 2003). The purpose of this document is to demonstrate seasonal land degradation monitoring in overgrazed rangelands by interpreting collected field data. The results indicate that over-grazing impacts soil conditions, plant communities and hydrological properties ultimately leading to increased flood and erosion risk. The data presented in this document were acquired in September 2025 during fieldwork conducted in the relatively ungrazed Ala Archa National Park and the heavily grazed Alamedin Gorge in Kyrgyzstan.

In rangeland ecosystems, land degradation is closely linked to the interactions among grazing intensity, soil properties, and vegetation cover. Overgrazing alters soil structure and vegetation composition, reducing infiltration and increasing runoff and erosion (Centeri, 2022). To understand these processes, several key parameters were quantified in this study, including soil infiltration, runoff potential, vegetation composition, soil type, aggregate stability, and soil compaction. Soil infiltration and aggregate stability determine how effectively water enters and moves through the soil, while soil type and compaction influences runoff generation and erosion susceptibility (Amézketa, 1999; Ekwue, 2010) Vegetation cover and composition play a critical role in regulating these dynamics by stabilizing soil and reducing surface flow (Hayati et al., 2018). Field work data was subsequently incorporated into the RHEM (Rangeland Hydrology and Erosion Model). RHEM is a process based webtool developed to simulate and predict runoff and erosion on rangelands and to evaluate the effects of conservation practices. It provides erosion predictions specifically tailored to rangeland environments and was parameterized using field experiments to quantify how the model handles infiltration, hydrology, vegetation, erosion mechanics, among other factors (Nearing et al., 2011).

Materials and Methods

Field measurements were carried out in two mountainous watersheds in the Tian Shan mountains, roughly 20 km south of Bishkek, Kyrgyzstan: The relatively ungrazed Ala-Archa National Park, a protected area where land use is prohibited, and the grazed Alamedin Valley, which is actively used for livestock grazing by the local population. Most of the Tian Shan mountains are grazed in the same ways as Alamedin Valley. Sampling sites were identified in Google Earth using parameters including longitude, latitude, elevation, topography, and land-use/land-cover characteristics. Based on a clear altitude gradient, field sites were then established at four elevations: 1500, 2000, 2500, and 3000 meters. At each site, a 30 m transect was established using a tape measure. Along this transect, ground cover, vegetation type, vegetation height, and soil compaction were assessed at 1 m intervals (n = 30) following the Line Point Intercept (LPI) method. At each point, a random location was chosen using a stick, and the vegetation type was identified according to the USDA classification key. Plant height and litter depth were measured using a tape measure from the soil surface to the tallest point. Soil compaction was measured with a pocket penetrometer, which was pressed vertically into the ground until the plunger reached the soil surface, at which point the reading was taken. Soil aggregate stability was evaluated using a Soil Aggregate Stability Kit (Forestry Suppliers, Item No. 78511). Soil samples were collected, submerged in water for five minutes, and visually compared to the stability standards provided with the kit. Soil infiltration was measured after clearing each sampling spot of litter, vegetation, and loose debris to create a flat, stable surface. The Mini Disk Infiltrometer (MDI) was filled with water, set to a suction of 1 cm, and placed on the soil surface. Once infiltration began, a stopwatch was started, and water volume (mL) was recorded at set intervals according to the device's flow rate.

Thirty infiltration measurements (n = 30) were collected across ten locations per site to capture spatial variability. At each site, ~500 g of soil was also collected for spectral analysis using a Near-Infrared (NIR) spectrometer. Each sample was placed on a tray, a blank scan was performed for calibration, and multiple points on the soil surface were scanned to quantify properties such as soil organic matter and soil moisture.

Results

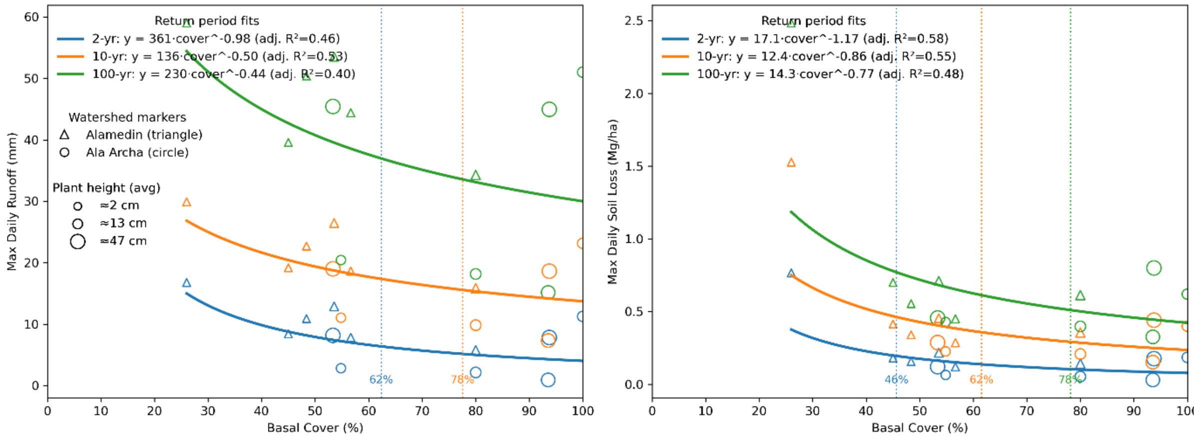

Figure 1: Basal vegetation cover as a control on runoff (left) and soil loss (right) under varying storm return periods. Symbols represent paired plots in Ala Archa (circles) and Alamedin (triangles), with point size scaled to average plant height. Dotted vertical lines mark cover thresholds (~46–78%) below which runoff and erosion accelerate rapidly.

With increasing basal cover (%), the power-law fits for the 2-, 10-, and 100-year storm events show a nonlinear decline in both maximum daily runoff (mm) and maximum daily soil loss (Mg/ha) (Figure 1). Triangles represent measurements from the Alamedin watershed, while circles represent those from the Ala Archa watershed. Marker size reflects the average plant height measured at each site. Each panel contains three fitted power-law curves describing the relationship between basal cover and the maximum daily hydrological response (soil loss and runoff) for the three return periods (the 2-, 10-, and 100-year storm events). All curves slope downward, indicating that greater basal cover consistently reduces both runoff and soil loss. The three vertically dashed lines highlight key basal-cover thresholds, percent cover values at which the reductions in runoff or soil loss become pronounced (46%, 62%, 78%).

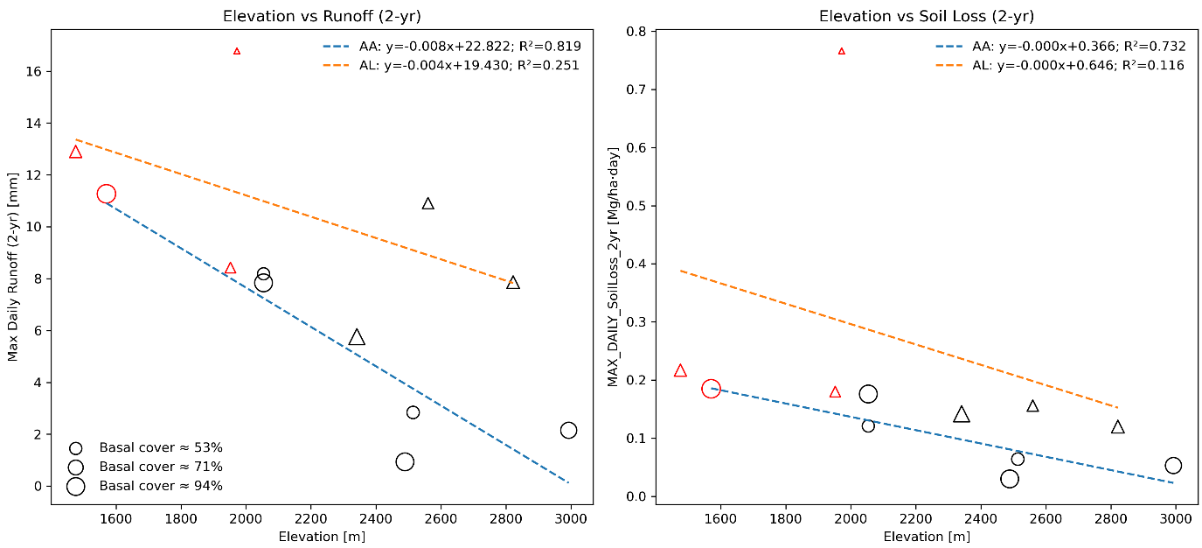

Figure 2: Elevation dependence of runoff (left) and soil loss (right) for 2-year storm conditions in ungrazed Ala Archa (AA) and grazed Alamedin (AL). The size of each marker is scaled with basal cover. Symbols represent paired plots in Ala-Archa (circle)

The effects of elevation (m) on maximum daily runoff (mm) and maximum daily soil loss (Mg/ha-day) for 2-year return period storm events in the Alamedin and Ala Archa watersheds are shown in Figure 2. Triangles represent the Alamedin watershed while circles represent the Ala Archa watershed; the marker size stands for the approximate basal cover (%) at the sampling location. Runoff decreases with increasing elevation in both watersheds; the Ala Archa watershed shows that max daily runoff decreases with increased elevation (R^2=0.819). and has a lower maximum daily runoff compared to the Alamedin watershed. The Alamedin watershed shows a weaker downward trend, showing that increasing elevation has no correlation with runoff (R^2=0.251). The lower elevation on both watersheds exhibits higher max runoff. Soil loss also declines with increased elevation, but with a smaller magnitude than runoff. The Ala Archa watershed suggests that increasing elevation has a positive correlation with soil loss patterns (R^2=0.732) whilst the Alamedin watershed has a flat slope, resulting in that elevation in the Alamedin watershed barely influences soil loss (R^2=0.116). Across both panels, larger markers are clustered at lower runoff and soil loss, even where elevations are similar. In contrast, smaller markers contribute disproportionately to higher runoff and soil loss, especially at lower elevations.

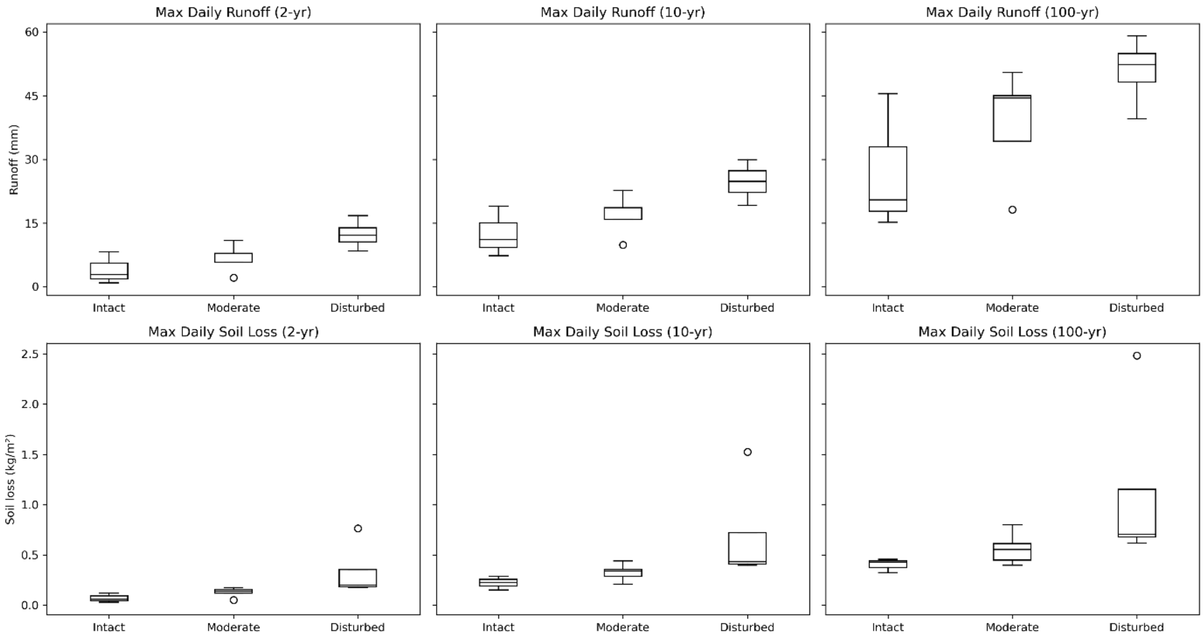

Figure 3: Maximum daily runoff (top row) and maximum daily soil loss (bottom row) across three land conditions; Intact, Moderate, and Disturbed, for rainfall events expected every 2, 10, and 100 years.

Runoff (mm) and soil loss (kg/m^3) across three land-condition types, Intact, Moderate, and Disturbed, are presented in Figure 3. We grouped study sites into one of the three land condition types using a combination of aggregate stability, plant height, basal cover, and observations that indicate grazing, like the amount of manure from horses, cows, sheep or yak. Intact soils have stable structure and continuous vegetation cover, Moderate soils show partial disturbance with some vegetation loss or surface compaction, and Disturbed soils are highly degraded with exposed, loose surfaces. The top row shows maximum daily runoff for 2-, 10-, and 100-year events. Runoff increases the more the land is disturbed, with intact soils generating the lowest and disturbed soils the highest runoff. Differences among land conditions are magnified under larger rainfall events. The bottom row depicts soil loss, which also increases with both rainfall intensity and land disturbance. Disturbed soils lose the most sediment, moderate soils show intermediate losses, and intact soils are the most resistant to erosion, highlighting the role of vegetation cover and soil stability in mitigating runoff and erosion.

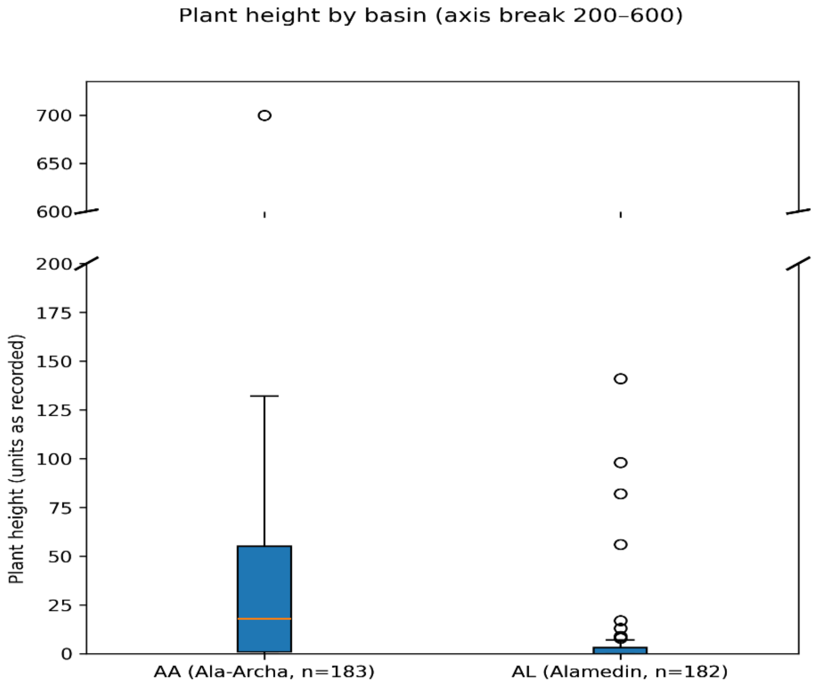

Figure 4: Recorded plant heights (cm) in the under grazed Ala Archa (AA) and the over-grazed Alamedin (AL) watersheds.

Differing plant heights between two watersheds is demonstrated in Figure 4. Median plant height is substantially greater in Ala Archa and exhibits a wider overall range of values. In Ala Archa most individuals fall below 50 units except a few extreme values producing a right-skewed distribution. In contrast, plant height in Alamedin was generally low, with the majority of observations clustering near the base of the axis. The axis break between 200 and 600 units indicates the presence of tall plants in the Ala Archa watershed. Compared to the more heavily grazed Alamedin watershed, the relatively less grazed Ala Archa watershed exhibits greater variability in plant height as well as taller vegetation overall.

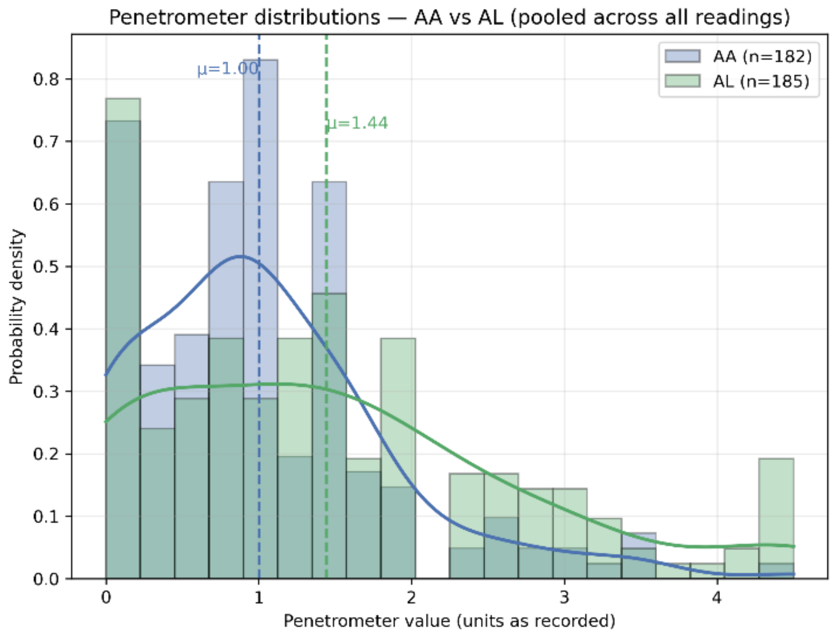

Figure 5: Penetrometer distributions, Ala Archa (AA) vs. Alamedin (AL) watersheds (pooled across all readings).

The distribution of penetrometer readings for the Ala-Archa (AA) and Alamedin (AL) basins is shown in Figure 5. The Ala Archa watershed exhibits consistently lower penetrometer values with relatively little variation, indicating that the soil is generally soft and less compacted. In contrast, the Alamedin basin shows higher readings with a wider range of values, reflecting soils that are more compacted and heterogeneous in structure. The difference between the watersheds is particularly evident in the upper range of readings, where the heavily grazed Alamedin basin demonstrates pronounced soil hardening compared to the relatively undisturbed Ala-Archa basin.

Conclusion

Overall, the results demonstrate how differences in grazing intensity drive ecological and hydrological contrasts between the Ala Archa and Alamedin watersheds, increasing basal vegetation cover is associated with a nonlinear decline in maximum daily runoff (mm) and soil loss (Mg/ha) for the 2-, 10-, and 100-year storm events (Figure 1). Power-law fits indicate that greater basal cover consistently mitigates hydrological response. Marker size reflects average plant height, linking vegetation structure directly to runoff and erosion patterns. As elevation increases, the relatively less grazed Ala Archa watershed shows a declining trend in runoff during a 2-year storm event (Figure 2), suggesting that higher elevation sites with lower grazing pressure maintain greater infiltration capacity. When runoff and soil loss are scaled by basal vegetation cover, these patterns illustrate how grazing intensity interacts with elevation to influence hydrological responses. The lone high-value point, also in Figure 2, represents a site with unusually high runoff and soil loss, likely due to localized surface conditions rather than elevation. This measurement was retained after verification, underscoring the influence of grazing on hydrological properties and highlighting that basal vegetation cover is a dominant control on runoff and soil loss across both watersheds. Runoff and soil loss across the three land-condition types found in field study areas, Intact, Moderate, and Disturbed, further illustrate these trends (Figure 3). Intact soils with continuous vegetation cover consistently produce the lowest runoff and soil loss, conversely disturbed soils with exposed and loose surfaces generate the highest. Moderate soils exhibit intermediate responses, and the differences among land conditions are magnified under larger storm events. Differences in plant height between the two watersheds (Figure 4) provide additional insight into grazing impacts. Median plant height in the relatively lightly grazed Ala Archa watershed is substantially greater and more variable than in the heavily grazed Alamedin watershed, which shows relatively short vegetation clustered near the base of the axis. The axis break between 200 and 600 units in Ala Archa reflects the presence of tall individuals, emphasizing how reduced grazing allows plants to achieve greater stature and structural complexity, which contributes to higher basal cover and soil protection. Soil compaction, measured by penetrometer readings (Figure 5), further underscores the effects of grazing by quantifying soil structure. Soil in Ala Archa is generally soft and less compacted, with relatively little variation, whereas Alamedin soils exhibit higher and more heterogeneous readings, reflecting pronounced soil hardening due to heavy grazing. The differences are most pronounced at the upper end of the distribution, indicating that overgrazing not only reduces vegetation but also alters soil structure, reducing infiltration and increasing susceptibility to runoff and erosion.

Taken together, these findings demonstrate a clear link between grazing intensity, vegetation structure, soil properties, and hydrologic response of the landscape to these forcings. Overgrazing in the Alamedin watershed leads to reduced basal cover, shorter vegetation, increased soil compaction, higher runoff, and greater soil loss, whereas the less grazed Ala Archa watershed maintains softer soils, taller and more variable vegetation, and lower hydrological losses. These results demonstrate the critical role of grazing management in maintaining soil stability, reducing erosion risk, and sustaining watershed resilience under variable storm events.

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