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Assessing the impact of overgrazing on soil erosion in arid regions at a range of spatial scales

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Abstract Increased livestock numbers in arid regions cause overgrazing which results in reduced infiltration and accelerated runoff and soil erosion. Results from a range of studies indicate that at the macro- and mesoscales soil erosion can increase dramatically due to overgrazing; causing increases of five to 41 times over the control at the mesoscale and three to 18 times at the macroscale. However, the establishment of simple relationships across the range of scales is difficult due to spatial variation of soil erosion rates and patterns. Water authorities should be actively associated with range management activities for the protection of arid zone drainage basins.

INTRODUCTION

This paper summarizes the outcome of a cooperative project, for which the main contributors are listed in the Acknowledgements section. The problems of grazing management and of hydrological stability are inseparable throughout the arid regions. In fact, grazing management has a far greater influence than forest policy on the hydrological regimes of arid, semiarid and tropical watersheds with higher rainfall intensities, less stable soils and longer dry seasons (Pereira, 1979). Increasing livestock numbers, exceeding the potential carrying capacity of rangelands, have been seen as a common cause of overgrazing in arid regions. Overgrazing causes destruction of vegetative cover by eating and trampling, disturbance of root systems by scuffling, and compaction of the surface reducing infiltration and accelerating runoff and soil erosion (Thomas & Middleton, 1994). In Iraq, overgrazing has reached the stage of causing soil erosion and has severely reduced the carrying capacity of the rangelands (Kaul & Thalen, 1971). Toebes *et al.* (1968) reported a nearly thirty-fold increase in runoff yield under a heavy grazing regime at Wagga Wagga, Australia. Mukinya (1990) provided data from three Kenyan rivers that suggest a ten fold increase in soil erosion between 1965 and 1986 due to overgrazing in their drainage basins. However, detailed data on the effects of grazing on basin hydrology in arid regions at a range of spatial scales are lacking. This paper deals with the impact of overgrazing on soil erosion in arid environments and attempts to provide realistic answers to such questions as "can intensive grazing be maintained without accelerating both overland flow and soil erosion?".

HYDROLOGICAL DATA

Data sources for the present study consist of:

(a) Microscale plot studies (Vich *et al.*, 1983; Sharma, 1993) conducted during 1982-1992 in the Divisadero Largo basin in the Piedmont and Precordillera region of the Andes Mountains to the west of Mendoza (33.0-33.5°S; 68.8-69.1°W), Argentina.

(b) Mesoscale studies of runoff and soil loss (Shankarnarayan *et al.*, 1987) conducted during 1979-1980 in the southwest of Jodhpur (26.2°N; 73.0°E), India.

(c) Meso- and macroscale sediment transport studies conducted during 1979-1987 in the Luni River basin located within the Indian Arid Zone (Sharma *et al.*, 1993). The range of spatial scales conforms to Becker's (1992) classification.

Six field plots of 10 m^2 area were established in the Divisadero Largo basin in 1982. Soils are shallow and undeveloped medium to fine sands. Vegetation yields low shrubby pastures of 5-45% cover depending on slope steepness. The plots were instrumented to record rainfall, runoff and sediment concentrations (Fernandez *et al.*, 1984). The area has a subtropical arid climate, and is characterized by convective summer thunderstorms. The mean annual precipitation is 201 mm, 77% of which falls during the summer months of October to March. The average annual temperature is 13°C. The dominant land use is indiscriminate grazing by cattle.

The five contiguous drainage basins with areas of 0.8 to 2.0 ha near Jodhpur have slopes of 3.6 to 8.0% and were instrumented to record rainfall, runoff and sediment concentrations in 1979. The soils are shallow to moderately deep sandy loam mantled with gravels and pebbles in places. Ecologically, the vegetation consists of thornscrub with locally adapted desert grasses having a basal cover of 1.9 to 4.6%. The whole area has been continuously overgrazed and eroded for many years. This region has a tropical arid climate and is characterized by monsoon rainfall. The mean annual precipitation is 360 mm, 87% of which falls during the summer months of June to September. The average annual temperature is 24°C. The five treatments, introduced in the rainy season were: control (undisturbed, no grazing), no grazing but shrubs removed (trees and grasses retained), and three grazing regimes viz. light grazing (1 cow ha^{-1}), moderate grazing (3 cows ha^{-1}) and heavy grazing (4 cows ha^{-1}) for 90 days.

The drainage basins in the Luni River basin range in size from 104 to 34 866 km^2. Hourly sediment concentrations were determined from samples collected using three to five US DH-48 depth integrating suspended sediment hand samplers simultaneously, employing the equal transit rate method as recommended by Jones (1981) for arid regions. Discharge measurements were by current meter and the velocity area method, according to the standard practice of the US Geological Survey. The resulting data allowed a reasonably accurate representation of the variation in sediment concentration during each flow event, as well as computation of suspended sediment discharge. Regions steeper than 10% in the Luni River basin are generally forested and under pasture and are grazed heavily.

RESULTS AND DISCUSSION

At the microscale the destruction of the vegetation cover by overgrazing accelerated overland flow and soil erosion. An exponential relationship was found between soil loss and the shear stress acting on the soil under different vegetation covers (Fig. 1). The shear stress acting on the soil is given by:

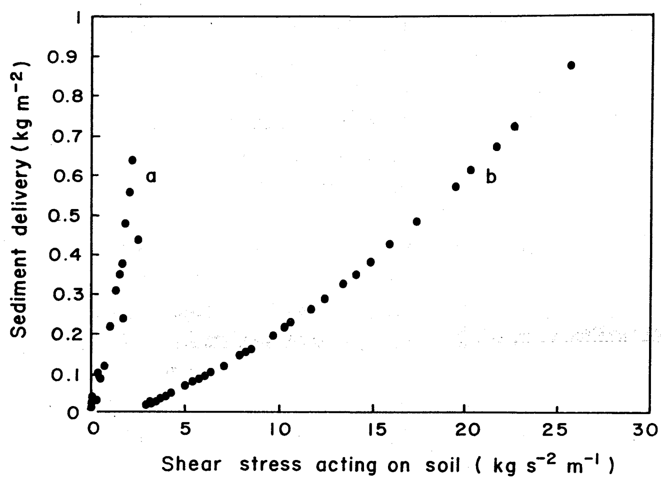

Fig. 1 Sediment delivery as a function of shear stress acting on soil for (a) 5%, and (b) 45% vegetative cover in the Divisadero Largo basin.

$$\tau_s = \gamma h S$$

where τ_s (kg m^{-1} s^{-2}) is the shear stress acting on the soil, γ (kg m^{-2} s^{-2}) is the weight density of water, h (m) is the runoff depth and S is the surface slope. Reduction in vegetation cover from 45 to 5% due to overgrazing increased soil erosion several fold. As an example, for a critical shear stress of 1.0 kg m^{-1} s^{-2}, the latter loses 0.22 kg m^{-2} of sediment whereas the former loses only 0.01 kg m^{-2} of sediment. Livingstone (1991) also observed an almost five times greater soil erosion under 20% vegetation cover than under 55% cover in Zimbabwe.

Both the peak flow and runoff yield increased with the severity of grazing in the mesoscale drainage basins (Table 1). Under heavy and light grazing regimes, the peak flow increased by about five and three times, respectively, over the control. Pereira (1979) also reported a five-fold increase in the peak flow in the Eppalock basin in Australia after the introduction of a heavy grazing regime. In the present study, runoff yield increased by about nine and two times over the control and light grazing, respectively. Penetration of rainfall into the trampled soil was slight; 0.5 m as against 1.25 m under the control. This may be attributed to a reduction in both the magnitude and available time for rainwater infiltration due to the destruction of

Table 1 Runoff and soil erosion under various grazing regimes.

Grazing regime	Peak flow (1 s^{-1} ha^{-1})	Runoff (mm)	Sediment concentration (g m^{-3})	Sediment (kg ha^{-1})
Undisturbed and ungrazed(control)	47.2	1.2	219	3.95
Shrubs removed	52.1	1.2	663	6.32
Light grazing	78.6	4.6	303	14.36
Moderate grazing	117.5	6.0	485	59.28
Heavy grazing	221.6	11.0	643	160.84
Standard error ±	32.1	1.8	89	29.72
Critical difference (5%)	89.1	5.0	247	82.50

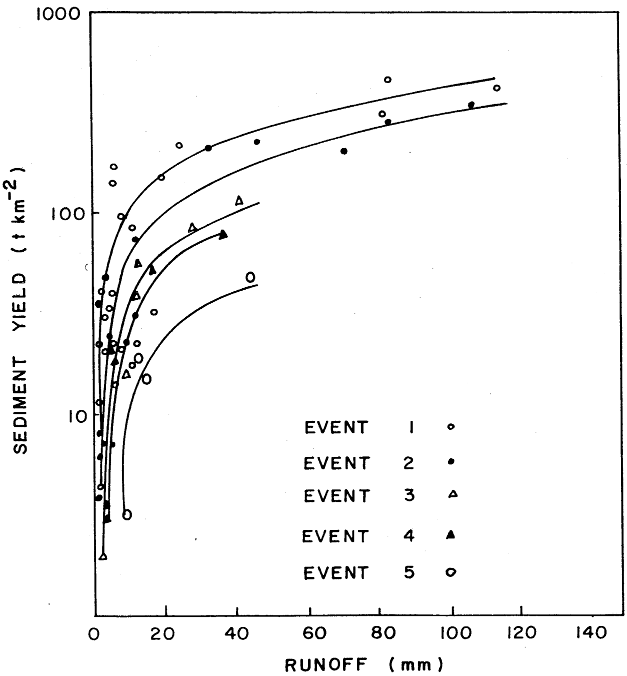

Fig. 2 Sediment yield in relation with runoff for sequences of storm events.

favourable soil structure by trampling. Loss of soil was directly proportional to the severity of grazing. Sediment concentrations under the heavy grazing regime (643 g m^{-3}) were almost double those under the light grazing regime (303 g m^{-3}) and about 1.5 times greater than those under moderate grazing (485 g m^{-3}). Removal of shrubs increased the sediment concentration by about 2.5 times (663 g m^{-3}) over the control. Increases in soil erosion due to introduction of grazing regimes in mesoscale basins were more pronounced. The soil loss increased by about 41 times under the heavy grazing regime relative to the control and 11 times relative to the light grazing regime. This may be attributed to the creation of loose soil aggregates through trampling by the cattle and the kinetic energy of increased runoff rates.

When sediment yields are plotted against the runoff generated by individual events for the macroscale drainage basins (Fig. 2); there is a general increase in sediment yield with runoff. The higher runoff is associated with greater kinetic energy for transport of the loose material generated by a heavy grazing regime. There are, however, striking differences in the rates at which sediment yield increases with runoff between the various flow events. This may be due to the presence of greater amounts of loose material to be transported in the drainage basin at the onset of the rainy season. The supply of this loose material decreases progressively during a sequences of storm events, due to shorter intervals that allow less overgrazing impact. On average, three to five flow events occur annually in the macroscale drainage basins. The overgrazing resulted in a 3 to 18 fold increase in soil erosion over the control, depending upon the dominant landform within these drainage basins. However, while sediment mobilization occurred in the macroscale drainage basins, significant sediment output is limited to the major flood flows. The large suspended sediment loads carried from overgrazed rangelands rapidly fill storage dams and severely limit the irrigation and power potential of rivers critical to the development of community resources.

Two opposing hydrological factors are demonstrated by the available evidence: firstly, control of grazing to preserve a grass cover and to prevent excessive soil exposure and trampling is an essential precaution against accelerated soil erosion and flood flows; secondly, improving the density and productivity of grassland decreases the total water yield. As with forest cover, protection of soil, preservation of water quality and moderation of flow patterns are achieved only at a substantial price in extra water use by the vegetation (IGN France, 1992). Water authorities need to be actively associated with any form of range management for the protection of arid zone drainage basins.

CONCLUSION

In the arid zone both the runoff and soil erosion due to overgrazing are unevenly distributed. Spatial variations in soil erosion patterns and rates complicate the establishment of simple relationships across the range of spatial scales.

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