SOIL EROSION IN ARID AND SEMI-ARID CLIMATES OF NORTHERN CHILE

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Nearly 75 billion tons of soils are eroded from the world's terrestrial ecosystems every year (Pimentel and Kounang 1998). Almost one-third of the world's arable lands have been lost to the processes of soil erosion in the past four decades (Pimentel et al. 1995). Countless studies have focused on trying to predict soil erosion worldwide. For example, Nearing et al. (1989) modeled soil erosion caused by the actions of water on hillslopes including detachment, transport, and deposition processes. Manoj et al. (2000) used geographic information systems and USLE to estimate soil erosion and sedimentation in India. Using similar methodologies, Yueqing and Yunglong (2006) evaluated soil erosion rates in China and found hat the largest amounts of soil loss occurred at the lowest portions of drainage areas.

The arid and semi-arid of northern Chile have been highly degraded due to a combination of reduced plant cover and the intense (but few) rainfall events common to the area. Overgrazing by livestock and indiscriminate deforestation have also contributed to the acute soil erosion (Pizarro et al. 2003). The most critical area in Chile in terms of soil erosion and land degradation is the Coquimbo Region (Benedetti and Pizarro 2006). However, a lack of quantitative information on the erosional processes in the region is currently a problem. Estimations of the magnitude of soil erosion with alternative management scenarios are especially needed so that proper management-based decisions can be made to mitigate the loss of soil resources.

The purpose of the study reported in this paper was to develop event-based regression equations for the prediction of soil erosion, soil deposition, and the net change in soil movement (the difference between soil erosion and soil deposition) in three provinces in the Coquimbo Region. The regression model for the three provinces was similar. While a variable representing a combination of measurements for a rainstorm event (see below) was included in the regression equations, separate regression coefficients were calculated each of the three provinces to accommodate decision-making needs for each of the provinces.

STUDY PROTOCOL

This study took place on selected sites in three provinces of the Coquimbo Region (Figure 1) covering an area of 40,579.9 km^2. Steppe conditions with abundant fogs on the coastal area of Elqui, dry and warm steppe in the interior area of Limari, and cold steppe in the mountains of Choapa characterize the variability of climates of the region. Analyses of the respective soils of the provinces revealed a sandy-clay loam soil texture for the Elqui Province and a sandy loam soil texture for the Limari and Choapa Provinces. Thirty study sites were located within each of the provinces with three rectangular sampling plots (1.2- by-10 m) established on each of the study sites. Thirty erosion pins (bicycle rays) were installed systematically at each of the plots to measure the soil erosion and soil deposition after rainfall events of 0.2 mm and larger that occurred in 2007, 2008, and 2009. Measurements of the distance between the tip of the ray and soil surface were the basis for determining soil erosion and soil deposition values.

Mean values of soil erosion and soil deposition were determined by the applying the method of Pizarro and Cuitiño (2002) based on the equation $Y = X$ (Da), where Y = the estimated soil erosion or soil deposition (tons/ha), X = the average depth of soil erosion or soil deposition (mm), and Da = soil bulk density (tons/m^3). There were no significant differences in the estimates of soil bulk density obtained from soil samples collected on the three provinces and, therefore, these estimates were pooled.

A continuously recording rain gauge was located on 18 of the 30 study sites to measure the total rainfall, average rainfall intensity, and maximum 1-hour rainfall intensity for each of the rainstorm events included in the study. These measurements were

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2
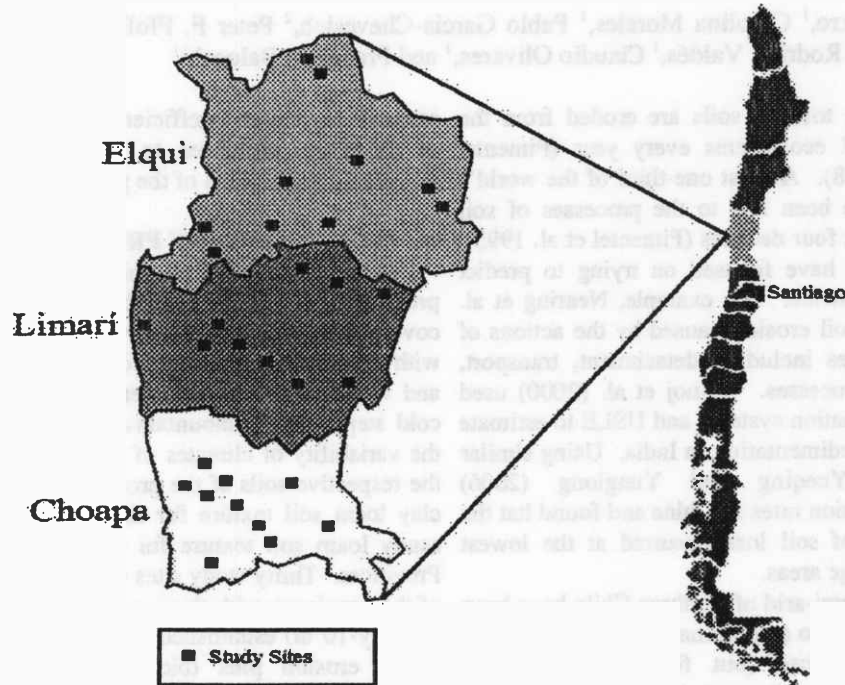
Figure 1. Location of the study sites in the Elqui, Limarí, and Choapa Provinces of the Coquimbo Region in northern Chile.

incorporated into an auxiliary variable representing these combined rainfall measurements for rainstorm events was included in the regression equations for each of the provinces.

RESULTS AND DISCUSSION

Higher total rainfall amounts were measured at the Choapa Province than the other two provinces but this province also had the lowest values for average rainfall intensity and maximum 1-hour intensity per rainstorm event. However, there were no statistical differences in average rainfall intensity or maximum 1-hour intensity per rainstorm event on the study sites of the three provinces.

The values for soil erosion, soil deposition, and net change in soil movement were not always significantly correlated with the rainfall measurements. For example, while highest amounts of soil erosion (5.2 Mg/ha) and net erosion (2.9 Mg/ha) were estimated for the Limarí Province, while

rainfall measurements indicated that the lowest the total rainfall (MTpp) and intermediate values of average rainfall intensity (IT) and maximum 1-hour rainfall intensity (Imax) per rainfall event for this province. However, the statistical values for the relationships between soil erosion, soil deposition, and net change in soil movement and the rainfall measurements were all positive and, therefore, regression equations were developed for each province.

The event-based regression equations to predict soil erosion (E), soil deposition (S), and net soil movement (En) for each of the three provinces are presented below. Adjusted coefficients of determination (r^2) and standard errors of estimation (SEE) for the respective equations are also shown.

Soil Erosion
E = [1.38 * X * P1] + [1.57 * X * P2] -
    [4.30 * X * P3]

where:

E = soil erosion (tons/ha)

X = the auxiliary variable = ln [MTpp + IT+ 1 / (Imax + 0.01)]

Pi = regression coefficients for the three provinces; for Elqui P1 = 1, P2 = 0, P3 = 0; for Limari P1 = 0, P2 = 1, P3 = 0; fr Choapa P1 = -1, P2 =-1, P3 = -1

$r^2 = 0.827$

SEE = 2.12 (tons/ha)

Soil Deposition

S =[0.626 * X * P1] + [0.704 * X * P2] - [1.90 * X * P3]

where:

S = soil deposition (tons/ha)

X = the auxiliary variable = ln [MTpp + IT + 1 / (Imax + 0.01)]

Pi = regression coefficients for the three provinces; for Elqui P1 = 1, P2 = 0, P3 = 0; for Limari P1 = 0, P2 = 1, P3 = 0; for Choapa P1 = -1, P2 =-1,P3 = -1

$r^2 = 0.526$

SEE = 1.94 (tons/ha)

Net Soil Movement

En = [0.750 * X * P1] + [0.8674 * X * P2] - [2.40 * X * P3]

where:

En = net change in soil movement (the difference between soil erosion and soil deposition (tons/ha)

X = the auxiliary variable = ln [MTpp + IT + 1 / (Imax + 0.01)]

Pi = regression coefficients for the three provinces; for Elqui P1 = 1, P2 = 0, P3 = 0; for Limari P1 = 0, P2 = 1, P3 = 0; for Choapa P1 = -1, P2 =-1, P3 = -1

$r^2 = 0.438$

SEE = 2.91 (tons/ha)

SEE values for the respective regression equations were less than 8 tons/ha, a value defined as the "maximum for sustainability" by Pizarro et al.(2004). Since no more than four rainstorm events meeting the minimum criteria for this study occurred annually in the region, the erosion rates currently estimated would still be sustainable. However, considering anticipated future rainfall events with a 10-year return period (MTpp = 120 mm, IT = 10 mm/h, Imax = 25 mm/h), the estimated soil erosion would be 6.7, 7.7, and 20.9 tons/ha for Elqui, Limarí, and Choapa, respectively, with the first two estimates "dangerously close" to the maximum sustainable values while the third estimate would be above it.

CONCLUSIONS

Measurements obtain from erosion pins is a useful method to develop predictive regression equations of soil erosion, soil deposition, and the net change in soil movement in the arid and semiarid environments of Chile as shown by this study. In considering such estimates, the results of this study suggest the need for mitigation activities in the Coquimbo Region since the relatively low return-period of rainstorms could cause significant rates of soil erosion, mostly in the Choapa Province.

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4

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