Watershed restoration reduces runoff and sedimentation from comparative watersheds in Pakistan's subtropical scrub zone

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ABSTRACT Two comparative watersheds of 81 ha represented some of the most severe erosion problems in the subtropical scrub zone of northern Pakistan. A traditional treated-control watershed study was used to evaluate the effectiveness of a comprehensive watershed restoration effort during calibration and treatment measurement periods totaling 9 and 5 years, respectively. Watershed restoration included tree planting, channel erosion control structures, and grazing management. Evaluation of watershed restoration success was based on the summer monsoon season when high intensity rains cause severe runoff and erosion. Covariance analysis of 141 storms over the life of the study showed that restoration reduced storm runoff and sediment yields by 55 and 78%, respectively. Supporting information suggests that the benefits of the watershed restoration program are even greater. The success of these watershed restoration practices demonstrates the potential for major improvements in the protection of Pakistan's vital irrigation system.

INTRODUCTION

Most of Pakistan is arid to semiarid. The largely agrarian economy is therefore dependent on massive irrigation works developed in conjunction with a few large dams in the Indus River system. The Mangla dam project on the Jhelum River is one example. Extensive abuse of watershed lands above the reservoir has resulted in accelerated erosion that is threatening the life of the reservoir. By one estimate, the life of the Mangla project could be extended about 45% by large scale watershed restoration
efforts (Huntting Technical Services, Ltd., 1961). Accordingly, a restoration program consisting of small engineering structures in gullies coupled with extensive revegetation and improved agricultural and range management practices has been in progress within the Mangla watershed for a number of years.

Some earlier studies quantified the effectiveness of alternative vegetation covers. Masrur & Hanif (1972) compared runoff and erosion from 4 m² sized plots representing bare soil conditions, good grass cover, and a pole size stand of Chir pine (Pinus roxburghii). Runoff was reduced by 63 and 85% by the Chir pine as compared to the good grass cover and bare soil conditions, respectively. The pine cover reduced sediment production by 99% relative to bare soil. Tree planting coupled with grazing control also provides effective control of surface runoff and erosion. Chir pine planting and elimination of grazing in the Balakot area reduced surface runoff by 57% and sediment production by 69% as compared to adjacent grazed areas with natural vegetation. A similar study in the Batagram area produced nearly similar results from Robinia planting and removal of grazing; surface runoff was reduced 43% and sediment production was reduced 59% (Abbas & Hanif, 1987). The present study expands the scope of the earlier work to the watershed scale and includes a variety of both engineering works and revegetation practices that are routinely installed on an operational basis. The study is in the sub-tropical scrub zone, an area that comprises a major source of accelerated sediment deposit into the Mangla reservoir.

THE STUDY AREA

The study area consists of two 81 ha study watersheds in the eastern half of the Potwar Upland at 33 degrees 10 minutes N latitude and 73 degrees 22 minutes E longitude (Fig. 1). The watersheds are in the Kanshi River basin, a tributary to the Jhelum River, which is a major source of water and sediment for the Mangla reservoir. The treated watershed lies along the Grand Trunk road, and the control watershed is about 0.5 km to the southwest. The upper half of the study watersheds consists of gently sloping (0 to 3%) agricultural land, whereas the lower half is steeper (9 to 16%) and severely eroded primarily by ravines and gullies up to 5 m deep (Fig. 1). Land holdings are small, scattered, and privately owned. Soils are deep, well drained, calcareous silt loams developed in late Pleistocene loess. Vegetation consists of scattered Acacia nilotica, Acacia modesta, Dalbergia sissoo, and Eucalyptus trees and various grasses, predominately Saccharum. Yearly average air temperature ranges from 21 to 26°C. Annual precipitation averages about 800 mm, most of which (about 65%) occurs as a series of intense storms during the summer monsoon season from July through September.
DATA COLLECTION

The study was conducted using a traditional control-treated watershed design utilizing calibration and treatment data collection periods. Data collection began in 1973 and was continued through 1986 as outlined by Beamish (1969). Each study watershed is instrumented with 1.8 and 0.15 m San Dimas flumes incorporated into one structure. The pair of flumes is capable of measuring a low flow of 0.014 m$^3$/sec and a peak flow of 11.3 m$^3$/sec. A continuous record of runoff depth is obtained from water level recorders augmented by periodic manual readings. Two sediment splitters are at the downstream end of each flume. Splitters direct varying rates of flow ranging from 1.6% of the flow at low water levels to 0.48 of the flow at high water levels into 6 by 6 by 1.5 m deep sediment settling basins. In the event of sediment basin overflow, periodic, volumetric samples are obtained and analyzed for sediment content. Sediment basin loss is calculated from the overflow rate sediment content data integrated over time. Sediment accumulations in the sediment basins are surveyed after each storm, and samples of the standing water are collected and analyzed for sediment still in suspension. Additional instantaneous sediment discharge data are obtained using DH48 samplers during the rise and fall of individual storm hydrographs.

Streamflow rates and sediment yields are measured for all runoff producing rainfall events during the monsoon period. From five to 18 such rainstorms occurred during the monsoon seasons of 1973 to 1986 for a total of 141 storms. A central weather station, equipped with recording and nonrecording instruments, is used to collect data on rainfall, air temperature, soil temperature, relative humidity, wind movement at 0.6 and 2.4 m height, and evaporation. An additional network of 10 rain gauges scattered throughout the study watersheds provides a measure of areal rainfall distribution (Fig. 1).

WATERSHED RESTORATION MEASURES

The watershed restoration program consisted of tree planting, control of grazing, and erosion control structures in channels. Minimal watershed restoration measures had been installed on both watersheds in 1960 and 1961 and included planting of about 8,100 trees and construction of 29 check dams and seven spillways in the treated watershed and planting of 3200 trees and construction of three spillways in the control watershed. Calibration ran from 1973 to 1981 during which time no new watershed restoration measures were installed on either watershed. Normal land use practices including farming and grazing were carried out on both watersheds during the calibration period. Treatment ran from 1982 to 1986 when additional watershed restoration measures were
Figure 1. Location map and detail of the study watersheds.
installed on the treated watershed including planting 30,000 trees, construction of 150 check dams, maintenance and improvement of spillways, and fencing to control grazing. No new watershed restoration measures were installed on the control watershed during the treatment period, and normal land use practices were continued as before. A vegetation survey conducted in 1984 illustrates the difference in grazing pressure on the two watersheds. Air dry production for all vegetation species except trees amounted to 1460 kg/ha on the treated watershed as compared to 490 kg/ha on the control watershed.

RESULTS AND DISCUSSION

The 81 ha study watersheds are flashy, responding rapidly to the monsoon rains. Extreme events are impressive. For example, peak flows generated by one 1985 storm on the control watershed exceeded the flume capacity of 11.8 m³/sec for a unit area discharge exceeding 14.8 m³/sec/km². Sediment concentrations during high intensity rains can exceed 30,000 ppm, and concentrations of 5,000 ppm are common even during low intensity storms. A typical flow hydrograph and sedigraph from the two study watersheds for a moderate sized storm in 1984 are shown on Fig. 2. Note the rapid rise and fall of the hydrograph and the extreme hysteresis exhibited in the sedigraph. In spite of the relatively low intensity rain (maximum intensity of 23 mm in 30 min), peak flows reached 1.4 and 2.7 m³/sec on the treated and control watersheds, respectively. Sediment concentrations were highest at the start of flow (7,200 ppm for the treated watershed and 21,000 ppm for the control) and fluctuated rapidly over time. The effectiveness of the watershed restoration measures is suggested by the fact that storm runoff was 75% greater on the control watershed and storm sediment yield was 200% greater as compared to the treated watershed.

Analysis of covariance was used to test for statistical differences in the storm runoff and sediment yields between the calibration and treatment periods. Logarithms of runoff and sediment yield were used in the analysis to minimize the problems of nonhomogeneity of variance associated with the variables. Runoff and sediment yields from the control watershed were used as the covariates in the tests and were highly significant in both cases (P<.01). There were highly significant reductions in both storm runoff and sediment yields as a result of the watershed restoration treatments (P<.01). Based on the averages adjusted for the covariates in each case, respective reductions in runoff and sediment yields amounted to 55 and 78% as a result of the watershed restoration program installed from 1982 to 1986 (Figs. 3 & 4).

It is likely that the reductions in runoff and sediment are even greater than 55 and 78%. A number of factors lead us to
Figure 2. Hydrographs and sedigraphs for the storm of August 5, 1984; a representative moderate intensity monsoon rainstorm (maximum intensity 2.3 mm in 30 min.) on the study watersheds.

suggest this. First, a fire on May 22, 1985 (probably caused by a cigarette tossed out along the highway adjacent to the watershed) burned over one-third of the experimental watershed. Second, the spillways on the three erosion control structures in the control watershed were raised 0.6 m during the summer of 1985. Observations in the area suggest that the vegetation cover on the burned area had been replenished by the end of the 1985 monsoon season. However, no records are available to document how fast the sediment storage areas behind the raised spillways were filled. The probable result of the fire and raised spillways would be to increase runoff and sediment yields from the experimental watershed as a result of the fire and to decrease runoff and sediment yields from the control watershed in 1985 and
Figure 3. Storm runoff before and after watershed restoration on the study watersheds. On average, storm runoff was reduced 55% by the treatment.

Figure 4. Storm sediment yields before and after watershed restoration on the study watersheds. On average, storm sediment yields were reduced 78% by the treatment.
possibly 1986 as a result of the added storage capacity behind the raised spillways. The net effect of these impacts would be to reduce the apparent benefit of the watershed restoration program based on a comparison of average runoff and erosion from the treated and control watersheds for the period from 1982 to 1986.

An additional factor comes into play in the evaluation of overall watershed restoration effectiveness in this area. For the entire calibration period from 1973 to 1981, monsoon season runoff and sediment yields were consistently lower on the treated watershed as compared to the control watershed (Table 1). On average, respective runoff and sediment yields on the treated watershed amounted to 70 and 60% of those from the control watershed. Inherent watershed differences may have caused the lower runoff and sediment yields on the treated watershed. It is also possible that the greater watershed restoration measures in place on the treated watershed at the start of the study contributed to some or all of the reductions in runoff and sediment yields. If this is the case, then this factor also suggests that the potential for watershed improvement is higher than the 55 and 78% reductions for runoff and sediment yields reported in the present study.

TABLE 1 Monsoon season precipitation, runoff and sediment yield for the calibration period. (1973-1981)

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<tr>
<td>1973</td>
<td>316</td>
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<td>63.3</td>
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<td>102</td>
<td>22.6</td>
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<td>92</td>
<td>4.3</td>
<td>6.2</td>
<td>0.6</td>
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<td>57</td>
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<tr>
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<td>394</td>
<td>108.3</td>
<td>141.7</td>
<td>21.4</td>
<td>9.6</td>
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<tr>
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<td>340</td>
<td>64.1</td>
<td>78.3</td>
<td>6.4</td>
<td>14.0</td>
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<td>19.9</td>
<td>0.7</td>
<td>5.9</td>
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<td>12</td>
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<tr>
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<td>384</td>
<td>55.4</td>
<td>115.7</td>
<td>5.1</td>
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<td>97.0</td>
<td>4.5</td>
<td>12.2</td>
<td>59</td>
<td>37</td>
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Finally, assuming that land management practices on the control watershed continue as they have during the treatment period, it is probable that the respective reductions of 55 and 78% in runoff and erosion will increase as the planted vegetation continues to propagate and grow on the treated watershed.
CONCLUSIONS

A watershed restoration program consisting of tree planting, grazing management, and channel erosion control structures reduced monsoon storm runoff and sediment yields by an average of 55 and 78% respectively. Consideration of (a) differences in watershed restoration measures installed prior to the present study (b) the effects of a fire in the treated watershed and raising the spillways in the control watershed and (c) the potential for continued reductions in runoff and sediment yields in the future, suggests that the respective reductions in runoff and sediment yields of 55 and 78% are conservative. The success of these watershed restoration practices demonstrates the potential for major improvements in the protection of Pakistan's vital irrigation system.

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REFERENCES


