ICARDA

Austrian
Development Agency

INTEGRATED WATERSHED DEVELOPMENT FOR FOOD SECURITY AND SUSTAINABLE IMPROVEMENT OF LIVELIHOODS IN BARANI, PAKISTAN

Supported by
Austrian Development Agency
CGIAR Targeted Funding

Final Report
December 2010

UNIVERSITY ARID AGRICULTURE 1994 RAWALPINDI

BOKU

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Contents

Background

Of the 22% of the world's land suitable for agricultural production, 5–7 million ha are being lost annually by land degradation, thus seriously threatening food security. Successful conservation of diminishing water and land resources and better livelihood strategies are needed to feed the ever-increasing population. The rainfed areas (Barani) in Pakistan cover about one million hectares and are home to about two million people, of which 70% live in rural areas and depend on agriculture for their livelihoods. The agricultural production system consists of upper catchments and gullied areas (56%), terraced fields (39%), and irrigated areas (5%). Gullied areas – natural forest and range area in the past – have degraded to abandoned land and expanded over arable land particularly during the monsoon. Monsoonal rainstorms also threaten the terraced fields, resulting into gully development. Irrigated agriculture has a low level of productivity. Landholdings are small and the majority of farmers live at a subsistence level, with insufficient resources to cope with crop failures due to either the effects of climatic variability or damage to terraced fields.

The depletion of natural resources is making it increasingly difficulty for the local population to get their livelihoods through farming activities. The results of this resource depletion and resource deficiencies are manifold and are mainly seen in the form of poor soil and water conservation measures, pressure on the available resources, and poor social coherence within communities. This in turn causes low productivity and deterioration of social infrastructure.

ICARDA, in association with the University of Natural Resources and Applied Life Sciences (Vienna), the Barani Agriculture Research Institute (BARI), the Soil and Water Conservation Research Institute (SAWCRI), the National Rural Support Program (NRSP) and the Pir Mahar Ali Shah Arid Agriculture University Rawalpindi Pakistan developed a project to study various options for sustainable improvement of livelihoods, while conserving the natural resource-base within an integrated watershed development framework. The Government of Austria provided the financial support for the project, which was implemented during 2007–2010 in the Dhrabi watershed near Chakwal.

The project focused on developing, demonstrating, and evaluating innovative and cost-effective technologies and methodologies for efficient monitoring and use of available water and land resources. This was aimed at sustainable improvement of livelihoods and protection of natural resources from degradation.

The project was implemented by adopting an integrated watershed development (IWD) approach. The IWD approach considers a watershed as a consolidated biophysical and socio-economic unit for development planning. It integrates the key elements of the watershed in a fashion that permits sustainable development for both human and natural ecosystems. The approach is holistic, multi-disciplinary, community-based, and participatory. It combines natural resource development and conservation with agricultural production and social development in a balanced framework. The major accomplishments of the project follow.

Watershed Selection and Characterization

Out of 30 potential sites, the Dhrabi watershed with an area of 196 km^2 was selected through a detailed survey and screening process. A watershed association was organized from 22 community organizations. A baseline survey of the area was conducted. Watershed and communities were characterized and community action plan was developed and implemented.

The watershed was characterized in terms of socio-economic conditions and natural resources in the upstream, middle, and downstream reaches. The total human population of the watershed is 27,438 people, with a greater population in downstream villages than upstream and midstream. The population density was 139 people/km^2 compared to an average of 166 people/km^2 for Pakistan. The average age of respondents was 54 years, and average family size was seven persons with a joint family system. In the upstream area, 87% were illiterate.

The rainfed upstream area had more small holdings (76%) compared to downstream (52%), which had 23% of holdings of size 5–10 ha. About 90% of the land downstream was eroded, compared to 70% upstream. About 75% of uncultivated rainfed land upstream was waste land. Over all, about 90% of cultivated land was allocated to wheat in Rabi (October–March) season and 10% to fodder during Kharif (April–September) season.

Water is a limiting factor for sustainable agriculture, with rainfall the only source, and with very high spatial and temporal variation. Therefore conservation and management of this resource is vital for agriculture development and socio-economic improvements in the area. In the irrigated upstream area, 70% of farmers were located at the head reach of the Nikka dam and 20% on the tail reach. About 10% of farmers had access to tubewell water.

Vegetation assessment both in upper- and under-stories was carried out in the area, and data for three seasons (winter, 2008: spring, and summer 2009) were collected. Stratification of the watershed area was done on the basis of altitude and three zones: upper, middle, and lower. From each zone, four sites were randomly selected and from each site there were four transects taken on the basis of soil physiography. These transects were from flat (F), gentle slope (GL, slope < 15°), steep slope (SL, slope > 15°), and gully bed (GB) areas. The average annual understory ground cover (herbaceous) was 62%, whereas the average vegetation cover provided by trees and shrubs was 19%. The average annual vegetation density (herbaceous) was 44 plants/m^2 and the vegetation density in terms of trees and shrubs was 158 trees or shrubs/ha. *Acacia modesta (phulai*) was the main contributing species among trees, with a composition of 70%, frequency of 52%, and importance value of 177.52.

Among grasses the area was dominated by *Heteropogon contortus* (*sariala*) and *Desmostachya bipinnata* (dab grass) with compositions of 24 and 21%, respectively; and frequencies of 32 and 45%. The importance values of these grasses were 77.97 and 61.94, respectively. The average height of the woody vegetation was 3.9 m, diameter 9.7 cm, and crown area 18.6 m^2. The overall carrying capacity of the watershed area was recorded as 10.2 ha per animal unit per year, which indicated that the rangeland was fair to good for grazing. The upper zone of the watershed was in relatively good condition compared to middle and lower zones in terms of vegetation health, most probably due to higher rainfall and lower livestock numbers. Steep slope areas and gully beds were richer with vegetation as compared to gentle slopes and flat areas.

Mott grass (*Pennisetum purporium*) plantations were successful in moist areas, less successful in shady areas, and sprouted well in gullied areas but did not survive due to long dry spells or scarcity of water.

Community Action/ Development Plans: Watershed Improvement and Rehabilitation

Watershed improvement/rehabilitation is an integrated and concentrated effort by all stakeholders, with communities in a stewardship role. Twenty two community organizations (COs) and a watershed associations (WAs) were organized. Based on the resource status of micro-watersheds, ecosystems, or small catchments, a community action plan (CAP) was developed. The CAP was evaluated for on- and off-site impacts, and those with overall positive impacts on livelihoods and the environment were approved and implemented with the communities.

Water and Soil Loss Monitoring and Management

Soil erosion is one of the most important land degradation issues in the watershed. A survey was conducted to determine the extent of erosion in the watershed. Permanent gullies and bank gullies were the main types of gullies in the watershed. Permanent gullies were deep and wide, and under cultivation in most places. Badlands were most prevalent in the lower watershed. The gully length was shorter in the middle watershed and eastern parts of the lower watershed. In the upper watershed, permanent gullies were longer and many gullies had not yet been converted to badlands. Bank gullies were more common in upper and lower parts of the watershed.

To estimate the extent of soil erosion under different land-use practices linked with rainfall-runoff, six sub-catchments of sizes 1.5–350 ha were selected for measurement of runoff and sediment yield. Runoff was measured through construction of stilling basins at the outlet of these catchments. Both bed and suspended loads were recorded. Bed load was measured at stilling basins upstream of weirs, while suspended load was measured through depth-integrated sampling tubes on an event basis. Micronutrients were also determined from the sediment samples collected. One automatic weather station, three recording rain gauges, and nine automatic water-level recorders were installed at different locations to cover the spatial variability in rainfall and runoff (Fig. 1). Innovative and cost-effective techniques were also introduced to reduce soil erosion.

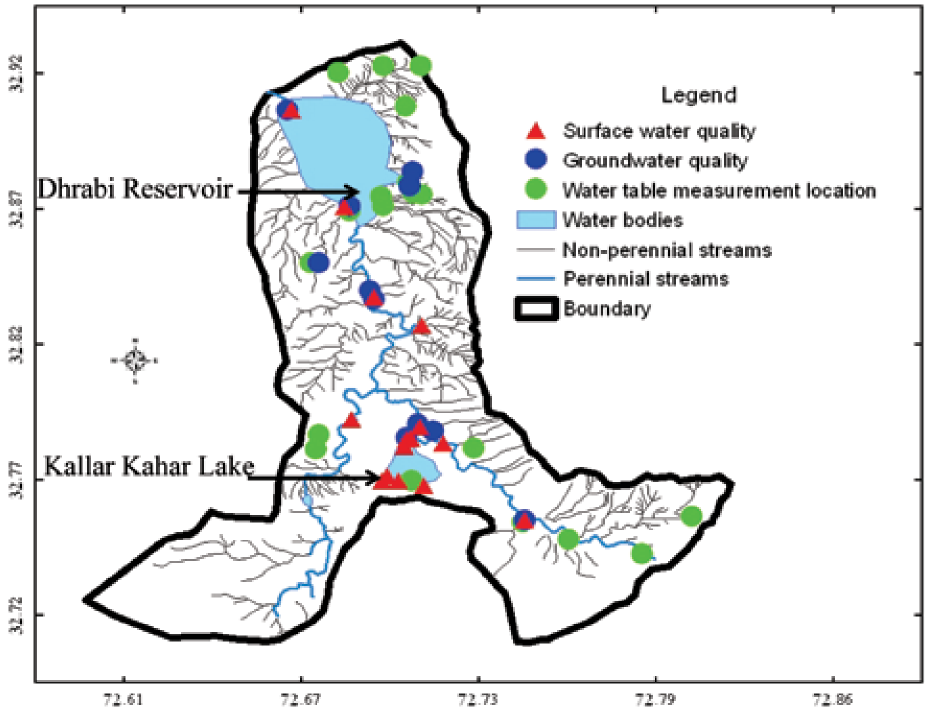

Figure 1. Map of the area, with instrumentation

Automatic weather station at Ratta Sharif

Arrangements for sediment monitoring

The rainfall data, collected during 1977–2009 at the Soil and Water Conservation Research Institute (SAWCRI) Chakwal, showed an average annual rainfall of 632 mm (Fig. 2); however, 52% of it occurred during July–September. During 2009, only 545 mm of rainfall was received. All runoff events were in summer, especially during the monsoon season, whereas winter rainfall was less intense. In 2009, intensity of rainfall events had a range of 50–100 mm/h. In 2010, rainfall intensity was generally 38–84 mm/h for the main rainfall events that caused most soil erosion. During 2009, 8–11 rainfall events produced runoff in these sub catchments. However, during 2010 there were 17–18 runoff events. Sediment yield of two small gully catchments had a range of 4.79–8.34 t/ha/y in 2009, a relatively dry year (annual rainfall 545 mm). However, during 2010 the sediment yield of the same catchments was 8.15–12.31 t/ha/y, indicating up to a 70% increase during the high rainfall year (annual rainfall 710 mm). The increase in sediment yield was due to an increased number of runoff-producing events, which were almost double during 2010 as compared to 2009. Terraced catchments with arable crops produced 4.10 compared to 12.31 t/ha/y of sediment in adjacent gullies, showing the potential of terraces to reduce soil erosion.

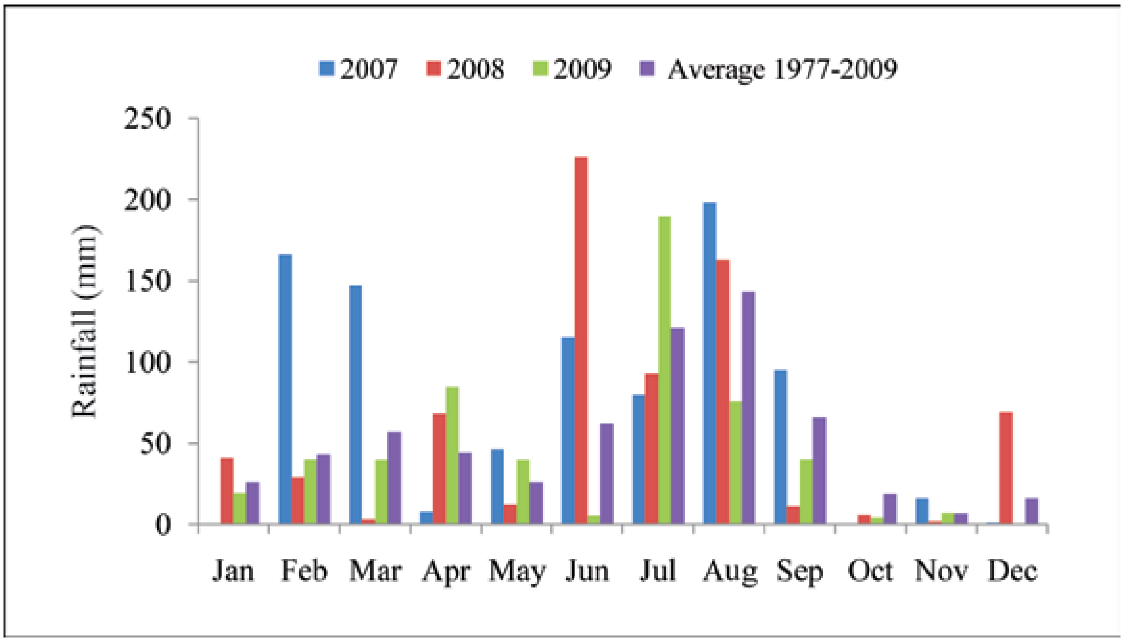

Figure 2. Long-term average rainfall at SAWCRI, Chawkal (during 1977-2010)

Runoff harvesting and soil conservation structures installed in gullies

Runoff was computed from the water level recorded in the streams. At Ratta and Rahna Sadat stream sites, data could not be recorded due to frequent silting up of the water-level recorder and changes in the flow path of the stream. HEC-HMS was used for event-based modeling of the watershed. The model was calibrated and validated for data of rainfall events and runoff recorded at Chak Khushi sub catchment. The model provided good agreement between the measured and the computed rainfall and runoff. However, the data were insufficient for application of the model to other sub catchments.

About 140 low-cost structures were constructed to conserve soil and moisture and to safely dispose of excess runoff. These structures helped control the degradation of the cultivable land and also trapped sediment coming from the catchments. On average, the sediment trapped by each structure was 273 kg/ha/y. The performance of these structures improved with time as they settled and grasses grew within the structure. These structures also helped conserve soil moisture by reducing runoff. The biological approach (i.e. growing of mott grass and *Atriplex canescens*) was also used to conserve the soil. However, due to uncontrolled grazing, most of these species did not survive.

Crop Yield Improvement through Crop Intensification and Diversification

In Pakistan, dryland farming is practiced on 12 Mha. Rainfall in these areas is low to medium, with high spatial and temporal variation. Over 50% of rainfall occurs during the monsoon in July–September, and therefore most rainfall is not available for cultivation. Moreover, due to conventional farming systems, the land and water productivity are very low. Therefore, there is a need to conserve as much rainwater as possible in the soil profile for subsequent use by crops or store it on the surface in the form of ponds, mini-dams, and small dams to be used as supplemental irrigation (SI). There is also a need to change the conventional farming systems through crop intensification and diversification to improve crop yields, water productivity, and farmers' net income. The following trials were conducted in farmers' fields to demonstrate how yield, water productivity, and net income could be improved: (i) rainfed wheat yield improvement with improved practices, (ii) evaluation of efficient irrigation techniques such as raised-bed sowing and small-plot sowing with SI, (iii) groundnut yield improvement under rainfed and SI conditions, (iv) summer and winter fodder improvement with improved practices and irrigation, (v) cultivation of crops in gullies, (vi) cultivation of high value crops, and (vii) application of gypsum for moisture conservation and yield improvement. A brief summary of the results is given below:

- With **improved practices**, on average yield of rainfed wheat was 31% higher compared to farmers' practices. Net income under improved practices was Rs. 70 000/ha (US$1 = Rs 72 in 2008–2009), almost double that under farmers' practices, showing that improved practices can give significantly higher returns in terms of land and water productivity compared to existing practices.

- Efficient **irrigation techniques** with SI can help improve wheat yield and water productivity. The highest wheat yield of 5102 kg/ha was obtained in small-plot sowing, which was 28% higher than farmers' practice, followed by raised-bed sowing (4776 kg/ha) at 24% higher. Water productivity in small-plot and raised-bed sowing was almost the same and about 23% higher than for the farmers' practice. The highest net income of Rs. 97 701/ha was for small-plot sowing, and was 35% higher than the farmer's practice. Under raised-bed sowing, net income was 30% higher than the farmers' practice. Therefore, with only 13% extra cost of water used as SI under small-plot sowing and with improved practices, there was 47% higher wheat yield and


Wheat sown in small plots and raised beds

55% higher net income compared to farmers' practices. Similarly, with about 12% additional cost of SI at critical growth stages of groundnut, its yield and net income were increased 4–7 times.

- Summer **fodder** under improved practices gave 27% higher yield and 30% higher net income compared to farmers' practice; similarly, winter fodder had increases of 34 and 31%, respectively. Mixed oats (*Avena sativa*)–berseem (*Trifolium alexandrium*) sowing provided 43 and 35% higher green fodder yields than single crops of oats or berseem, respectively; with net income from oats–berseem being 42–52% higher. Since berseem requires huge amount of water, its cultivation in rainfed areas seems to be uneconomical; the same amount of water can be used as SI for wheat or other crops that can give higher returns.

- Growing **high value crops**, where water is available, gives higher returns. Off-season coriander (*Coriandrum sativum*) and chilies (*Capsicum annum*) gave net returns of about Rs. 100,000/ha, whereas growing flowers gave a tremendous net return of > Rs. 700,000/ha. However, the production cost of high-value crops is relatively high. Therefore, only those farmers who can afford high investment can grow these crops.

- Growing **millet and sorghum** (*Sorghum bicolor*) in gullies with improved practices gave green fodder yields of 44,167 and 48,611 kg/ha, respectively; and the corresponding net income was Rs. 37,449/ha and Rs. 41,004/ha respectively. Therefore, cultivation in gullies not only conserves soil from further deterioration but also generates some income for farmers.


Off-season coriander and chili crops in the field

- Application of gypsum helped store moisture in the soil profile and increased crop yield. The treatment of gypsum (plus loose-stone structures) conserved 40% more moisture than control; and wheat grain yield (4501 kg/ha) and water productivity (1.5 kg/m^3) were 62% higher than control with a net return of > Rs. 100,000/ha. The highest groundnut pod yield of 1502 kg/ha was obtained under gypsum (plus stone structures), and was 50% higher than control.

Surface and Groundwater Monitoring

Water quality monitoring is an important component in maintaining a healthy watershed. The surface water quality of the watershed was monitored at 16 locations (Fig. 3) at regular intervals for its suitability for irrigation during 2007–2010. Similarly, the groundwater quality was monitored at 10 locations for drinking and irrigation purposes. The status of wastewater disposal in the watershed was also studied.

There was high spatial and temporal variability in surface water quality. The surface water quality at certain locations was poor and exceeded the permissible limits for irrigation purposes. Even in the Dhrabi Reservoir, the surface water quality was inferior to that found in most of the reservoirs of the area The electrical conductivity (EC) and residual sodium carbonate (RSC) either exceeded or fluctuated around permissible limits throughout the monitoring period at most locations. Therefore, the use of such water for irrigation needs special care or its prolonged use may .pose soil salinity and sodicity problems

The trend of groundwater quality was very similar to surface water quality, with high spatial and temporal variability. The following strategies may be useful to handle the issue of low water quality: (i) reduce the entry of high RSC water into the reservoir. Since Kallar Kahar Lake and its catchment are the main contributors of high salinity, therefore no water should be allowed to overflow from the lake. This may be done by raising the dikes of the lake (ii) using chemical amendments such as gypsum in the field to reduce the

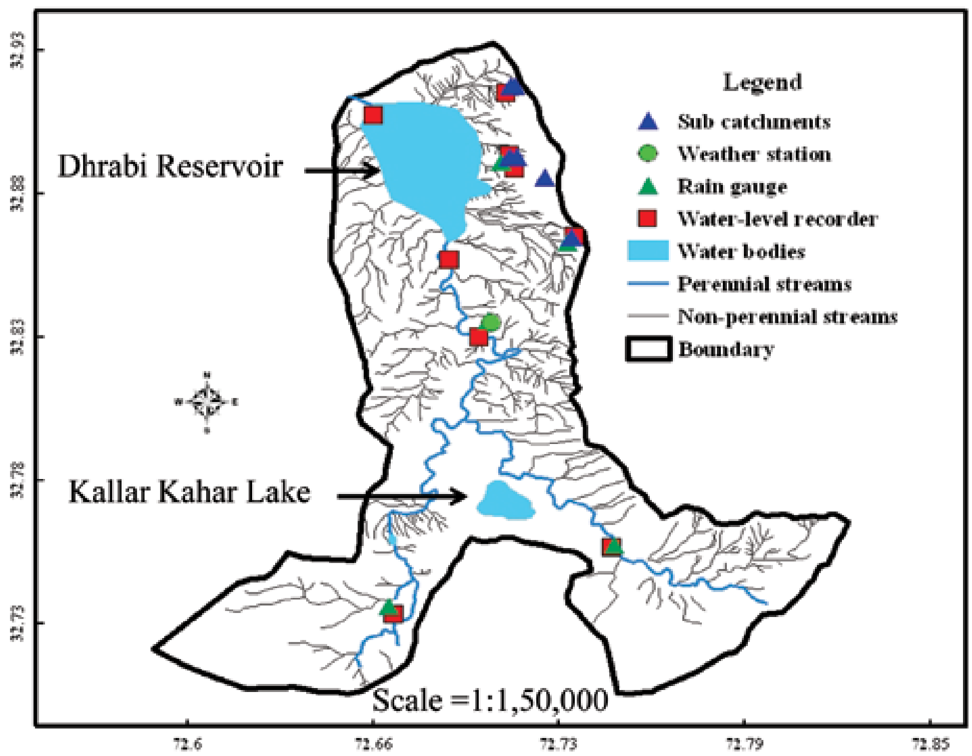

Figure 3. Map of the area, showing monitoring points

negative impacts of the sodic water; and (iii) adopting an appropriate cropping pattern.

Groundwater is also used for drinking purposes. Microbiologically, two out of eight points were found fit for drinking during August 2009, one out of eight samples during February 2010, and one out of 10 samples were fit during June 2010. Similarly, the microbiological quality of the Dhrabi Reservoir was unfit for drinking. Microbiological contamination of drinking water is responsible for directly or indirectly spreading major infections and parasitic diseases such as cholera, typhoid, dysentery, hepatitis, giardiasis, cryptosporidiosis, and Guinea-worm infections. This water requires proper treatment before use.

Soil samples were collected from the catchment areas of the major polluting streams and also from the beds of the Kallar Kahar Lake and the Dhrabi Reservoir. The soil samples from the catchments showed high salinity and sodicity that may be the cause of high salinity and sodicity in the streams. The highest EC, sodium adsorption ratio (SAR), and exchangeable sodium percentage (ESP) in the bed samples from the Kallar Kahar Lake were about 43 dS/m, 56, and 45, respectively. The high EC, SAR, and ESP in the bed were due to the saline water brought into the lake with runoff, and the evaporation from the lake increases salinity in the water. The salts ultimately settle at the bottom thereby increasing the salinity and sodicity. The EC at the bed of the Dhrabi Reservoir was also high (up to 5.1 dS/m) with an ESP of 4.3. The Dhrabi Reservoir became operational during 2007, and the salinity and sodicity level in the reservoir indicate that salinity and sodicity in the reservoir bed will likely increase with time. Small dams, mini dams, and ponds are the main source of groundwater recharge in the area. Since sodic soils reduce the soil permeability considerably, the recharge to the groundwater will be reduced substantially. There is a need to conduct a systemic study on the effect of saline–sodic water on groundwater recharge.

Kallar Kahar is the only major town generating wastewater in the watershed. The biochemical oxygen demand and chemical oxygen demand of the wastewater outside the exit points of Kallar Kahar were found to be within permissible limits.

Runoff and Sediment Yield Modeling

Long-term annual runoff and soil loss, as well as sediment yield, leaving the area were calculated using the simulation models RUSLE and WEPP. The necessary climate input data were obtained from a nearby weather station as well as from long-term observations in Islamabad. The digital elevation model and the land use/land cover map were derived from Aster satellite images taken in June 2006 and December 2007. For land cover and soil data, additional field measurements and laboratory analyses were carried out.

Simulation runs were performed for two time scenarios:

- For a period of 100 years generated from observations in Islamabad,
- Using measured climate data of Chakwal SAWCRI station from 2009.

Runoff and sediment yield measurements performed in 2009 and 2010 in a 2-ha watershed were used to verify WEPP simulations. The comparison between observations and simulations showed satisfactory agreement. For the 100-y simulation, the current land use without soil conservation measures was used. For the 2009 scenario, the applications of soil protection structures in the agricultural areas were also simulated – these structures consisted of stones which divert excess rainfall in a non-erosive way. It was assumed that rainstorms of 100 mm with an intensity of about 15 mm/h will not cause overflow. For a 100-y simulation period, an average surface runoff of 66 mm from the whole watershed without soil conservation structures was calculated. Using climate data from 2009, an annual surface runoff of 25 mm was predicted. When applying protection structures to the areas used for agriculture, the annual runoff could be reduced to 18 mm (i.e. 28% reduction). Retention of rainwater in the watershed leads to increased available water and will increase crop yields.

Soil erosion processes occurred on 75% of the watershed with mean rates of 82 t/ha/y, this relates to an average loss of 5–6 mm annually. On 25% of the area, eroded soil was deposited at 97 t/ha/y. This dislocation of soil results in a high variability of soil fertility and productivity within the area, and it affects the storage and filtering function of the soil. Dense forests, perennial trees, and grassland are the best land-use systems for protecting soil against erosion. Agricultural fields with low biomass production, bare fields and low vegetative cover were major sediment sources in the investigated watershed; and soils with high runoff potential showed the highest erosion rates. Considering the climatic conditions of 2009, the average soil loss could be reduced by 21% from 48 to 38 t/ha/y by implementing soil conservation structures on all areas used for agriculture. Not all of the eroded sediment was deposited within the area.

The 100-y simulation period produced a mean sediment yield of 25 t/ha/y. This amount of sediment creates problems with siltation of the reservoir and impairs water quality of the river and surface water bodies. For the 2009 scenario, a mean sediment yield of 13 t/ha/y was calculated; however, a reduction of 8 t/ha/y (38%) could be achieved by applying soil conservation measures. The simulation results showed that the implementation of the suggested soil conservation measures reduced surface runoff and soil loss. The decreased sediment yield will improve water quality and reduce off-site damage caused by erosion.

Nevertheless, land use systems with annual erosion rates of > 40 t/ha in major parts of the watershed and high deposition within the area are not sustainable. Additional soil protection measures and, in some parts of the watershed, also land use changes need to be considered to achieve the ultimate goal of sustainable land management.

Training and Capacity Building

The capacity building of the farmers and the local institutions was an integral component of the project. Capacity building of the communities included improving their knowledge in sustainable use of the resources and protection of the resource-base, building their capacity in communal decision-making and uses of common resources, and improving their interactions with the other stakeholders that directly or indirectly affect the watershed health and services.

Improving capacity building of the institutions in watershed planning, management, and development was achieved through formal trainings. It also included support to Masters and PhD studies in collaboration with

Participants of the on-the-job training programs

advanced research institutions/universities, enhancing interactions between academics and field staff, arranging formal training in relevant fields, and study tours of policy makers. The following training was arranged for the participating organizations and farmers:

- A study visit to Turkey to study the watershed management project – six participants
- Training on rainwater harvesting and water management at ICARDA, Syria – three participants
- On-the-job training on rainfall-runoff and sediment monitoring, water management, and productivity – 48 participants
- Farmer training/field days – about 600 farmers
- Field visit to the Mangla watershed – 15 participants
- Training on tree plantation and management – six COs (3000 plants distributed through mobile nurseries)
- Student training and theses – eight local and two Austrian. Details are shown in Table 1.

Table 1. Students who conducted their graduate research within the watershed project

Name	Title of Research	Field/ Degree	Status
Sana-ul-Haq	Assessment of productivity and carrying capacity of range vegetation of Dhrabi watershed	MPhil, Forestry & Range Management (regd. 2008)	Completed
Zohaib Hassan	Comparison of economic benefits between natural vegetation and terraced field crops in Dhrabi watershed area	MPhil, Forestry & Range Management (regd. 2008)	Completed
Muhammad Aslam	Social issues of upstream and downstream watershed communities of Dhrabi Dam	MSc Anthropology (regd. 2008)	Completed
Muneeb Ahmad	Economic analysis of small dam investment in Pothwar	MSc Economics (regd. 2008)	Completed
Muhammad Nadim Iqbal	Assessment of sediment yield of gullied system in Dhrabi watershed	PhD (regd. 2008)	Ongoing
Thomas Buchsbaum	Estimation of soil erosion in the Dhrabi watershed using RUSLE	MSc BOKU University	Completed
Warakorn Rataaneekul	Assessment of soil erosion and sediment yield in the Dhrabi watershed, using WEPP model	PhD BOKU University	Ongoing

Table 2. Final research report components and authors

Component	Authors
1. Socio-Economic and Natural Resources Characterization of Dhrabi Watershed, Pakistan	A. Khaliq. T. Oweis, A. Mahmood, S. Nizami, M. Ashraf, A. Majid and A. Ali
2. Improving Land and Water Productivity in the Dhrabi Watershed of Pakistan	A. Mahmood, T. Oweis, M. Ashraf, M. Aftab, N. Khan Aadal, I. Ahmad, M. R. Sajjad and A. Majid
3. Assessment of the Natural Resources Degradation and Options for Improvement- A Case Study from Dhrabi Watershed Pakistan	M. N. Iqbal, T. Oweis, M. Ashraf, B. Hussain, A. Ali, A. Majid and G. Nabi
4. Spatial Analyses of Water Quality in the Dhrabi Watershed of Pakistan: Issues and Options	M. Ashraf, T. Oweis, A. Razzaq, B. Hussain and A. Majid
5. Soil Erosion Assessment in Dhrabi Watershed of Pakistan	A. Klik, W. Rattanaareekul, and T. Buchsbaum

Austrian ambassador participation during the project annual planning meeting

Project team meeting with farmers