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Soil quality index response to land use change in Barog Dhillon watershed, Himachal Pradesh

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Abstract
The current investigation aimed for determining the Soil Quality Index (SQI) across various land use categories—namely agricultural land, forest land, grassland, and scrubland—within both project and non-project areas of the Barog-Dhillon watershed in Solan district, Himachal Pradesh. A comprehensive field investigation was undertaken, involving random sampling and the collection of site-representative soil samples from two depths: 0-15 cm (surface) and 15-30 cm (sub-surface). Among the land use types, forest land exhibited the most favorable physical, chemical, and biological characteristics, registering the highest SQI scores within the watershed project area: 0.71 at the surface and 0.61 at the sub-surface depth. In the non-project area, forest land also showed relatively high SQI values—0.67 for the surface and 0.56 for the sub-surface—classified under Group 3 and Group 2, respectively. Conversely, scrubland recorded the lowest SQI values: 0.51 (surface) and 0.39 (sub-surface) in the project area, and 0.42 (surface) and 0.31 (sub-surface) in the non-project area, corresponding to Group 2 and Group 1. Overall, SQI values were consistently higher in the watershed project area compared to the non-project area, underscoring the beneficial effects of watershed development interventions. These outcomes indicate that the adoption of scientifically designed soil and water conservation practices within watershed management frameworks can significantly enhance soil quality across various land uses. The comparative analysis further reinforces that agricultural lands, in particular, benefit from improved soil productivity and quality under such programs.

Keywords: Soil Quality Index (SQI), land use types, soil and water conservation

Introduction
Soil quality plays a vital role in sustainable land management, directly impacting ecosystem productivity, water regulation, and the preservation of biodiversity. It represents the soil's capacity to carry out key ecological functions, including nutrient cycling, moisture retention, and the support of plant growth (Bünemann *et al*., 2018) [2]. In recent years, interest in soil quality evaluation has increased, particularly in ecologically sensitive and rapidly changing landscapes such as the mid-Himalayan region, where land use transformations are both common and often intensive.

The Soil Quality Index (SQI) is a comprehensive metric used to assess soil health by integrating essential physical, chemical, and biological attributes into a unified quantitative value. It enables comparison across land use types and management regimes, offering valuable insights for sustainable agricultural and environmental planning. Land use changes, such as deforestation, agricultural intensification, and grazing, significantly affect soil structure, fertility, and microbial activity, thereby altering soil quality.

The Barog-Dhillon watershed, located in the Solan district of Himachal Pradesh, features a heterogeneous landscape comprising multiple land use types such as forest, agricultural areas, grasslands, and scrublands. This region is characterized by its ecological sensitivity and susceptibility to soil erosion, particularly in non-project areas where conservation measures are lacking. Watershed development programs, when effectively implemented, have the potential to enhance soil health through improved vegetation cover, reduced runoff, and better nutrient cycling.

Evaluating SQI across different land uses and soil depths in both watershed project and non-project areas is essential to understand the extent of soil degradation or improvement under varying land management practices. Such assessment can help in identifying priority areas for

intervention and guide policy frameworks focused on soil conservation and productivity enhancement.

This study seeks to evaluate the Soil Quality Index (SQI) under varying land uses at two depths (0-15 cm and 15-30 cm) in the Barog-Dhillon watershed. The findings aim to enhance the understanding of how land use patterns and watershed development initiatives influence soil health, providing valuable insights for sustainable watershed and land use planning in the Himalayan region.

Study area and scope

This research, entitled "Soil Quality Index Response to Land Use Change in Barog Dhillon Watershed, Himachal Pradesh," was undertaken in Solan district, part of the mid-hill region of the state. This study was centered on the Barog-Dhillon micro-watershed, covering a total geographical area of approximately 556 hectares. The watershed development project, undertaken with a financial allocation of ₹3.0 lakh, aimed at promoting soil and water conservation as well as ecological restoration through scientific monitoring and sustainable land management practices.

Location and Climate

The Barog-Dhillon watershed is situated within the mid-Himalayan agro-ecological zone of the Solan district, Himachal Pradesh. Geographically, it lies at a latitude of 30°50′533″ N and longitude of 75°5′947″ E, with elevation ranging from 1500 to 1950 meters above mean sea level. The area is characterized by rugged, undulating terrain composed of hills, slopes, and depressions, predominantly facing the southeastern direction. Climatically, the region falls under the broad sub-tropical category, yet due to its elevation, it also displays transitional temperate features. It experiences significant seasonal temperature variation, with summer highs reaching up to 37°C and winter lows dropping to around 1°C. The mean annual temperature is around 19.8°C, with the highest temperatures typically occurring in May and June, and the lowest in December and January. Frost occurrences during winter are common and often restrict natural vegetation regeneration, although snowfall is infrequent. The watershed receives an average annual rainfall of nearly 1150 mm, most of which occurs during the southwest monsoon season (June to September). This monsoonal precipitation plays a vital role in sustaining soil moisture levels and maintaining the overall hydrological balance of the watershed ecosystem.

Land Use Classification

The Barog-Dhillon watershed encompasses diverse land use systems, each exerting varying influences on soil quality due to differences in vegetation cover, anthropogenic disturbance, and management practices. For this investigation, four predominant land use types were identified based on ecological relevance, spatial extent, and influence on soil health indicators: Agricultural Land, Forest Land, Grassland, Scrub Land.

Scope of the Study

The selected land use systems were studied in both watershed project areas (with active implementation of soil and water conservation measures) and non-project areas (with no such interventions). This facilitated a comparative analysis of their impact on the Soil Quality Index (SQI) and associated physical, chemical, and biological properties of the soil across two depth intervals: 0-15 cm (surface layer) and 15-30 cm (sub-surface layer). Given the topographical complexity, climatic variability, and land use diversity, the Barog-Dhillon watershed presents an ideal case for evaluating how different land management practices and conservation interventions influence soil quality in mid-Himalayan landscapes.

Materials and Methods

Collection and Preparation of Soil Samples

A random sampling method was used following field survey and stratification based on land use distribution in the Barog Dhillon watershed. Sampling was conducted in September, covering both watershed project and non-project areas. A total of 16 soil samples were collected—8 from each area, representing four land use types: agricultural land, forest land, grassland, and scrubland. For each land use, two depths were sampled: Surface (0-15 cm) and Subsurface (15-30 cm). Samples were air-dried in shade, then divided into two parts: One part was ground and sieved (2 mm) for analysis of bulk density, particle density, and water holding capacity. The other was left unprocessed for aggregate size distribution. This protocol ensured data consistency while preserving key physical characteristics of the soil for accurate laboratory evaluation.

Soil quality assessment

The assessment of soil quality in both project and non-project areas of the watershed is fundamentally based on the careful selection of relevant soil indicators. This evaluation integrates a comprehensive set of parameters across three major categories: physical, chemical, and biological properties. Physical attributes include bulk density (BD), particle density (PD), porosity, maximum water holding capacity (MWHC), water-stable aggregates (WSA >0.25 mm and <0.25 mm), mean weight diameter (MWD), and infiltration rate. Chemical properties encompass soil pH, electrical conductivity (EC), cation exchange capacity (CEC), organic carbon content, and the availability of essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), along with micronutrients like zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn). Additionally, exchangeable bases—calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+})—are considered. The biological dimension of soil quality is represented by the total microbial count, which serves as an important indicator of soil biological activity and health.

Soil Quality Index (SQI)

SQI estimation in this study followed the standardized procedures described by Jha and Mandal.

Scoring Technique

Initially, the most appropriate indicators reflecting different soil functions were selected. These indicators were then assigned unitless standard scores on a 0-1 scale based on their importance. A 'more is better' approach was applied to parameters such as organic carbon and infiltration rate, whereas a 'less is better' approach was used for indicators like bulk density and particle density. The ranking was guided by the critical limits of each parameter. A score of 1 indicated the highest potential functional capacity for the respective system

Weight

The weighting of indicators was carried out in accordance with the procedure described by Andrews *et al*. (2002) [1].

Integration

Each normalized value (scaled between 0 and 1) was multiplied

by its corresponding weight, reflecting its relative importance. The cumulative sum of these weighted indicators, representing key soil functions, was used to determine the overall soil quality score, denoted as Q.

$Q = q_{bd}w_{bd} + q_{pd}\, w_{pd}$ ……

Where
Q: Overall soil quality index
q_{bd}: Rating for bulk density
w_{bd}: Weight assigned to bulk density
q_{pd}: Rating for particle density
w_{pd}: Weight assigned to particle density

The SQI was derived using the equation provided below:

$SQI = \Sigma\, W_i\, S_i$

Where:
Wi: Weight factor for the *i*th indicator, derived from Principal Component Analysis (PCA) Si: Score assigned to the *i*th soil variable (normalized on a 0-1 scale)

The Soil Quality Index (Q) was classified into three defined categories to interpret the overall soil condition:

1. Low: $Q < 0.33$
2. Medium: $0.33 \leq Q \leq 0.66$
3. High: $Q > 0.66$

Results and Discussion

The physical, chemical, and biological indicators evaluated in this study (Figures 1, 2, 3, and 4) were scored according to their significance in influencing soil quality across both project area and non-project area of the watershed. A "more is better" approach was applied to parameters that positively contribute to soil health, including porosity, water-stable aggregates (>0.25 mm), and maximum water holding capacity; hydraulic parameters including infiltration rate; chemical characteristics such as pH, EC, organic carbon, CEC, available macro- and micronutrients, and exchangeable cations (Ca^{2+}, K^{+}, Mg^{2+}); along with biological indicators, including total microbial count. In contrast, indicators such as bulk and particle density, fine water-stable aggregates (< 0.25 mm), and levels of exchangeable sodium (Na^{+}) were evaluated using a "less is better" approach, as elevated values of these properties typically signify degraded soil conditions.

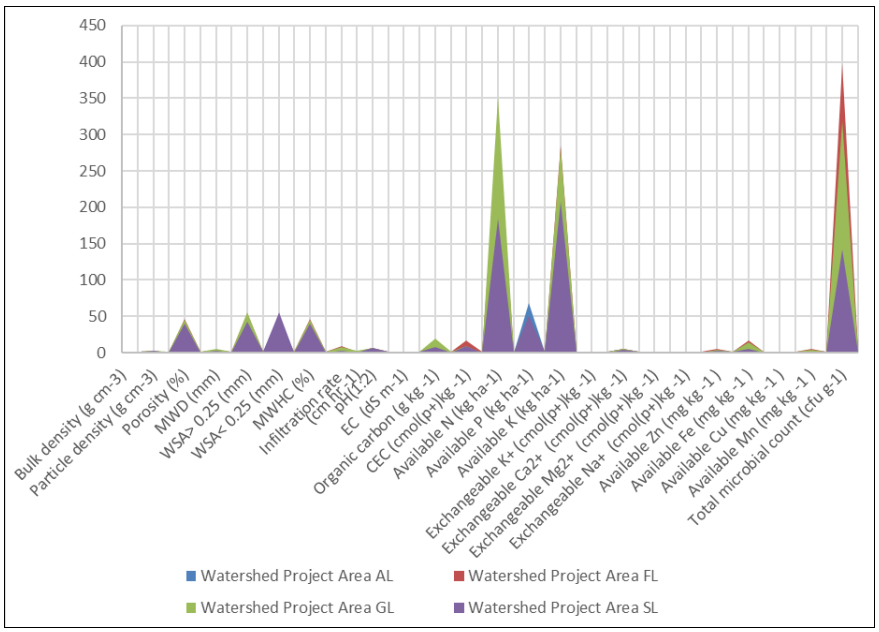

Fig 1: Mean Values and Rating of Soil Attributes (0-15cm) Across Land Use Types in the Watershed Project Area

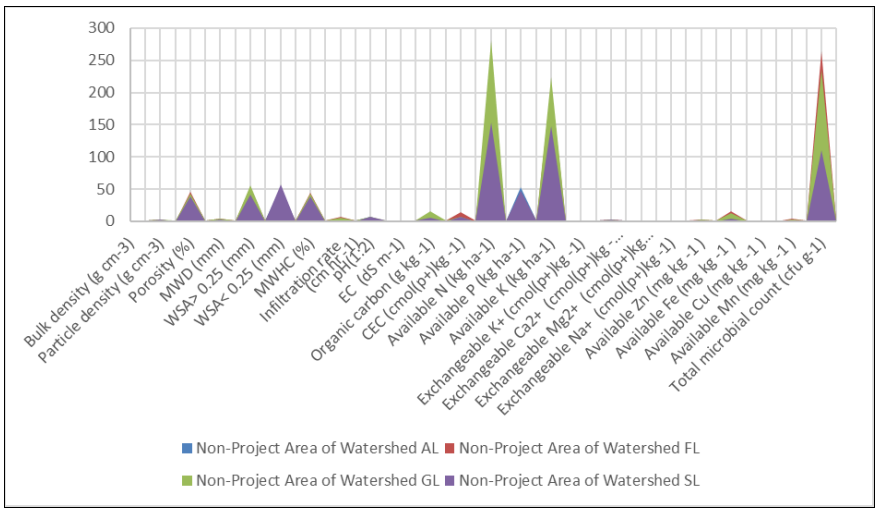

Fig 2: Mean Values and Rating of Soil Attributes (0-15 cm) Across Land Use Types in the Watershed Non-Project Area

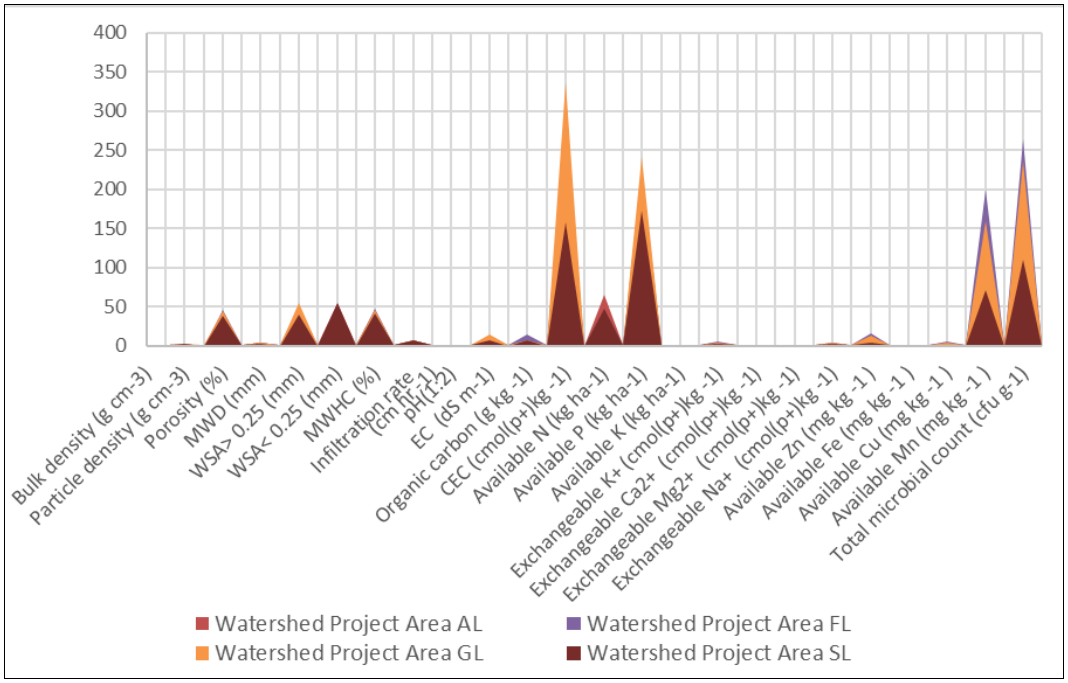

Fig 3: Mean Values and Rating of Soil Attributes (15-30 cm) Across Land Use Types in the Watershed Project Area

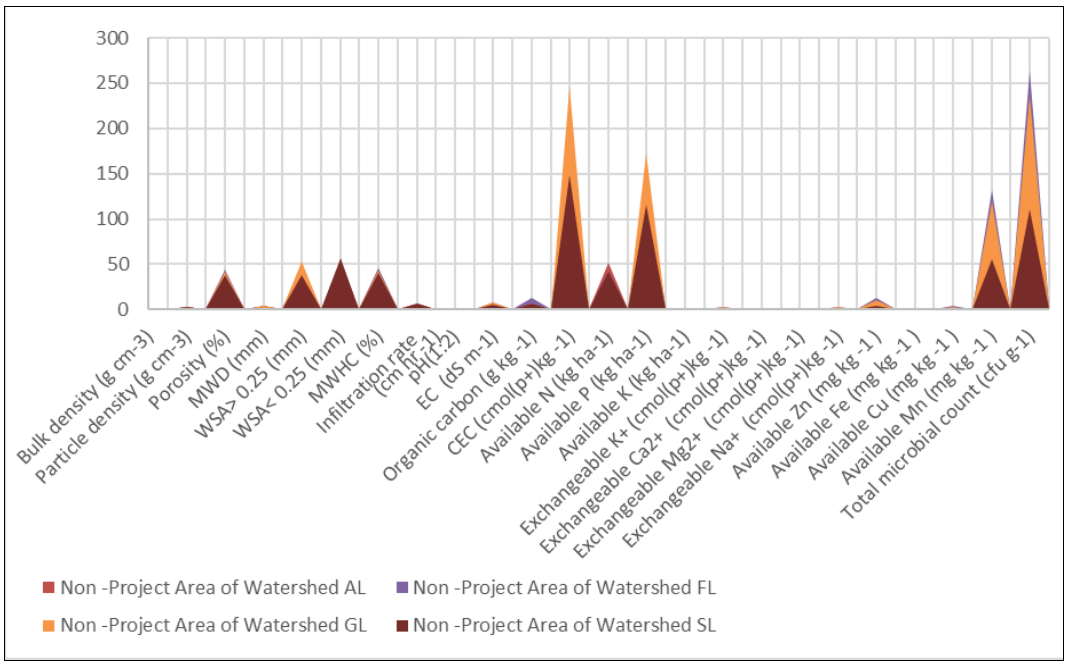

Fig 4: Mean Values and Rating of Soil Attributes (15-30 cm) Across Land Use Types in the Watershed Non-Project Area

Soil Quality Index Evaluation Under Various Land Uses

An examination of the data presented in Figures 5 and 6 reveals that soil quality index assessed at both surface and sub-surface depths soils in the project area of the watershed ranged from 0.51 to 0.71 and 0.39 to 0.61, respectively. In contrast, the non-project area exhibited SQI values ranging from 0.42 to 0.67 for surface soils and 0.31 to 0.56 for sub-surface soils. To evaluate overall soil performance, aggregated SQI scores were computed for different land use systems. Among the land uses, forest soils recorded the highest SQI values—0.71 (surface) and 0.61 (sub-surface) in the project area, and 0.67 (surface) and 0.56 (sub-surface) in the non-project area—placing them in Group 3 and Group 2, respectively. In contrast, scrubland soils had the lowest SQI values: 0.51 (surface) and 0.39 (sub-surface) in the project area (both classified as Group 2), and 0.42 (surface) and 0.31 (sub-surface) in the non-project area, belonging to Group 2 and Group 1 categories, respectively. The relatively lower SQI values in scrubland can be attributed to the generally poor performance of key soil parameters used in SQI computation. Conversely, the higher SQI in forest land can be linked to elevated levels of crucial physical, chemical, and biological soil attributes, which contribute positively to soil quality. Dadhwal *et al.*, (2011) [3] also reported higher soil quality index for forest soils. On the basis of soil quality index, Forest lands exhibited the highest values, followed by grasslands, agricultural lands, and scrublands in descending order.

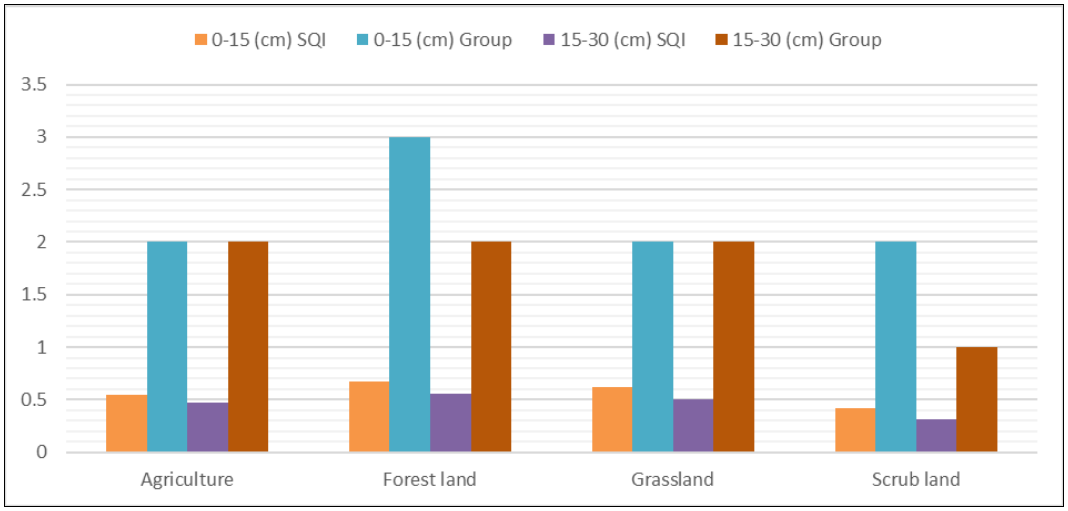

Fig 5: Soil Quality Index (SQI) of Watershed Project Area

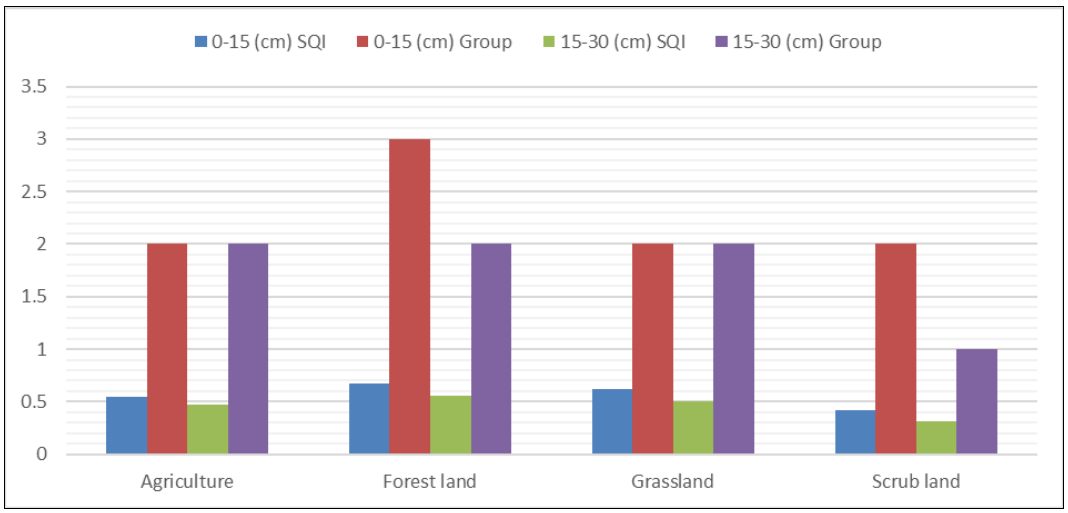

Fig 6: Soil Quality Index (SQI) of Non Project Area of Watershed

Summary and Conclusion

The assessment of the SQI across various land uses in watershed, revealed significant variations in soil health parameters influenced by different land management practices. The evaluation integrated critical physical indicators (such as bulk density, porosity, water-stable aggregates, and infiltration rate), chemical indicators (including pH, electrical conductivity, cation exchange capacity, organic carbon, and available N, P, K, along with key micronutrients), and biological indicators to compute a comprehensive measure of soil quality. Among the evaluated land uses, forest and grassland ecosystems recorded higher SQI values. This was primarily due to their superior soil structure, elevated organic carbon content, and enhanced nutrient availability, all resulting from minimal disturbance and consistent organic matter input through litterfall and root biomass. In contrast, scrublands and intensively cultivated agricultural areas exhibited comparatively lower SQI values, which were attributed to decreased organic matter, soil compaction, and nutrient loss from erosion. Notably, areas under watershed management interventions demonstrated improved soil quality relative to non-project areas. This improvement highlights the positive impact of conservation practices including afforestation, establishment of check dams, and the use of vegetative barriers in restoring soil health and promoting sustainability. In conclusion, land use plays a critical role in determining soil quality. Sustainable land management practices are essential for maintaining and enhancing soil health, especially in fragile hilly ecosystems. The promotion of less intensive land use systems—such as agroforestry, silvipasture, and conservation agriculture—alongside continued watershed management efforts, can significantly improve soil health and contribute to prolonged agricultural performance and ecological resilience in the Barog-Dhillon watershed.

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