



Assessment of Soil Physical Properties of Barog Dhillon Watershed in Solan District of Himachal Pradesh under Different Land Uses

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present investigation was conducted to assess the physical characteristics of soils under various land uses—agricultural land, forest land, grassland, and scrubland, in a project and non-project areas of the Barog-Dhillon watershed Solan district, Himachal Pradesh. A survey of random sampling was carried out, and representative soil samples were collected from two profiles of depth: 0–15 cm and 15–30 cm. Indicators for soil physical health assessment included bulk density,

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particle density, porosity, aggregate size distribution, maximum water holding capacity, cumulative infiltration and infiltration rate characteristics of soil. The highest bulk density was observed in scrubland, with mean values of 1.57 and 1.60 g cm⁻³ in the surface and sub-surface soils of the watershed project and non-project areas, respectively. In contrast, grassland exhibited the lowest bulk density, with values of 1.30 and 1.32 g cm⁻³ in surface and sub-surface soils of the respective areas. Similarly, the highest particle density was recorded in scrubland soils (2.67 and 2.72 g cm⁻³) while grassland soils showed the lowest, at 2.35 and 2.40 g cm⁻³, in the project and non-project areas, respectively. The highest average porosity values, 45.95% and 44.98%, were recorded under forest land use in both soil layers. The proportion of soil aggregates larger than 5 mm was greatest in forest land, with average values of 8.23% and 7.97% (surface) and 8.31% and 8.05% (sub-surface) in the project and non-project areas, respectively. Scrubland soils had the lowest values (2.58%, 2.30% and 2.30%, 2.02%, respectively). Maximum water holding capacity was also highest in forest land (45.25% and 46.26%) in surface and sub-surface layers of the project and non-project areas, while the lowest was noted in scrubland (38.91% and 41.38%). Infiltration rate followed a similar trend, highest in forest land (9.1 and 6.6 cm hr⁻¹) and lowest in scrubland (2.8 and 2.0 cm hr⁻¹). Cumulative infiltration was also greatest in forest soils (45.8 and 33.0 cm) and lowest in scrubland (14.00 and 10.20 cm), across both watershed categories. The study clearly indicates that soils within the watershed project area possess superior physical properties compared to the non-project area, highlighting the positive impacts of watershed management practices.

Keywords: Soil physical properties; land use; watershed management; bulk density; water holding capacity; infiltration rate.

1. INTRODUCTION

Soils are the foundation of terrestrial ecosystems, playing a pivotal role in supporting plant growth, regulating hydrological cycles, cycling nutrients, and buffering pollutants. Among the various soil characteristics, physical properties such as bulk density, porosity, aggregate stability, infiltration rate, and water holding capacity are crucial determinants of soil quality and productivity (Adhikari & Hartemink, 2016). These physical attributes influence root development, aeration, microbial activity, and the ability of the soil to store and transmit water and nutrients—factors that are critical for sustainable land management and agricultural productivity.

In recent years, changes in land use and land cover (LULC) driven by population growth, deforestation, agriculture intensification, and infrastructure development have emerged as major drivers of soil degradation, particularly in fragile ecosystems such as the Indian Himalayas (Singh *et al.*, 2025). These alterations in land use led to variations in vegetation cover, organic matter inputs, and soil biological activity, all of which directly affect soil physical properties. Forests and natural grasslands, characterized by dense vegetation and minimal disturbance, typically enhance soil structure and porosity, increase organic matter content, and promote aggregate formation. In contrast, scrublands and

poorly managed agricultural lands often suffer from compaction, erosion, and loss of soil structure due to intensive cultivation, overgrazing, and lack of vegetative cover (Zhang *et al.* 2024).

The Barog Dhillon Watershed, located in the Solan district of Himachal Pradesh, represents a diverse mid-Himalayan landscape characterized by varying land use systems—agricultural lands, forest lands, grasslands, and scrublands. It offers a unique opportunity to study the effects of these different land uses on soil physical properties under real-world conditions. Moreover, the region has been the focus of watershed development programs aimed at restoring soil and water resources through measures such as afforestation, check dams, contour bunding, and vegetative barriers. Such interventions are designed to reduce runoff, enhance infiltration, and restore degraded soils (Hermassi *et al.*, 2025).

Understanding how land use types affect soil physical properties is essential not only for evaluating the effectiveness of watershed management interventions but also for informing land use planning and policy. Studies have shown that forested and well-managed grassland ecosystems generally exhibit lower bulk density, higher infiltration rates, and greater water holding capacity compared to degraded or intensively

cultivated areas (Ewunetu *et al.*, 2025). These physical advantages result from the accumulation of organic matter, the presence of stable soil aggregates, and minimal soil disturbance. On the other hand, continuous cultivation and unplanned grazing often lead to soil compaction, reduced infiltration, and increased erosion susceptibility (Centeri, 2022).

Despite the growing recognition of the importance of soil physical properties in sustainable land management, there remains a lack of localized, empirical data specific to micro-watersheds in the western Himalayan region. This gap is particularly evident for project areas undergoing watershed interventions versus non-project areas, where land degradation may be more pronounced. Therefore, an in-depth study comparing soil physical properties under different land use types in both managed and unmanaged conditions can provide critical insights into the region's ecological health and resilience.

Against this backdrop, the present investigation titled “Assessment of Soil Physical Properties of Barog Dhillon Watershed in Solan District of Himachal Pradesh Under Different Land Uses” was borne. The objectives of the study are to assess and compare key soil physical properties—bulk density, particle density, aggregate distribution, infiltration rate, and water holding capacity—across different land uses in both watershed project and non-project areas. The findings are expected to offer valuable inputs for soil conservation strategies, optimal land use planning, and long-term sustainability of watershed ecosystems in the mid-Himalayan region.

2. STUDY AREA AND SCOPE

The Barog in the mid-hills of Himachal Pradesh. The study focused on the Barog-Dhillon micro-watershed, which spans a total area of approximately 556 hectares. The watershed project, aimed at soil and water conservation as well as ecological restoration, was supported with a financial outlay of Rs. 3.0 lakh for development and monitoring activities.

2.1 Location and Climate

Geographically, the study site lies within the Barog-Dhillon watershed, situated in the mid-Himalayan zone of Solan district. The watershed is positioned at 30°50'533" N latitude and 75°5'947" E longitude, with an elevation range

between 1500 to 1950 meters above mean sea level. The area is characterized by a rugged and undulating topography, comprising hilly terrains interspersed with natural depressions and slopes that generally face the southeastern direction.

Climatically, the region is classified as sub-tropical, although it displays transitional characteristics toward a temperate climate due to its elevation. The area experiences significant seasonal variations in temperature, with summer maxima reaching up to 37°C and winter minima dropping to nearly 1°C. The mean annual temperature is around 19.8°C, with May and June being the hottest months, and December and January marking the coldest period. Occasional frost events during winter hinder natural vegetation regeneration, although snowfall is infrequent. The region receives a mean annual rainfall of approximately 1150 mm, the bulk of which occurs during the southwest monsoon season (June to September), contributing significantly to the soil moisture regime and hydrological balance of the watershed.

2.2 Land Use Classification

The Barog-Dhillon watershed displays diverse land use systems that influence soil characteristics through varied vegetative cover, land management, and disturbance regimes. For the purpose of this study, four dominant land use categories were identified and selected based on their ecological significance, extent of coverage, and potential impact on soil physical properties:

- **Agricultural Land:** Actively cultivated areas under seasonal crops with varying management intensity. The main crops grown in the area were wheat (*Triticum aestivum*) and maize (*Zea mays*). In addition to these, some vegetable crops such as tomato (*Solanum lycopersicum*), capsicum (*Capsicum annuum*), and cauliflower (*Brassica oleracea*) were cultivated as cash crops.
- **Forest Land:** Areas dominated by natural or planted tree cover, often contributing organic matter and aiding in soil conservation. The forests comprised species such as Chir (*Pinus roxburghii*), Babool (*Dalbergia sissoo*), Khair (*Acacia catechu*), and bamboos.
- **Grassland:** Open landscapes primarily consisting of native and introduced grasses, often used for grazing or left

fallow. The main species found in the grasslands included black spear grass (*Heteropogon contortus*), dhoob grass (*Cynodon dactylon*), sabai grass (*Eulaliopsis binata*), plume grass (*Saccharum ravennae*), *Apluda mutica*, *Cymbopogon martini*, and others.

- **Scrub Land:** Degraded lands with sparse vegetation, generally dominated by shrubs and characterized by low biomass and high erosion susceptibility. The shrubs commonly found in the scrublands included kasmal (*Berberis lycium*), bhek (*Prinsepia utilis*), lantana (*Lantana camara*), and tirmir (*Zanthoxylum armatum*).

These four land use systems were studied in both watershed project areas (with soil and water conservation interventions) and non-project areas (lacking such interventions), enabling a comparative assessment of their effects on key soil physical parameters such as bulk density, particle density, aggregate stability, infiltration rate, and water holding capacity. The selected watershed, with its varied land uses and intervention strategies, thus provided a suitable and representative site for evaluating the influence of land use practices on soil physical health in the mid-Himalayan context.

3. MATERIALS AND METHODS

3.1 Collection and Preparation of Soil Samples

A random sampling technique was adopted to collect representative soil samples following a comprehensive field survey and stratification based on the spatial distribution of distinct land use classes. Sampling was carried out in the month of September, covering both the watershed project area and the non-project area of the Barog Dhillon watershed.

The soil samples were collected from the project area and the non-project area. Within each area, samples were obtained from four dominant land use classes: agricultural land, forest land, grassland, and scrub land. For each land use category, two depth intervals were considered:

- **Surface soil:** 0–15 cm
- **Subsurface soil:** 15–30 cm

This resulted in four samples per depth layer in each area, allowing for a comprehensive comparison of soil physical properties across land use types and management conditions. Each collected soil sample was air-dried under shade at room temperature. Once dried, the sample was divided into two equal parts:

- One part was processed by manually grinding with a pestle and mortar, followed by sieving through a 2 mm mesh to ensure uniform particle size for further physical property analyses such as bulk density, particle density, and water holding capacity.
- The second part was kept unprocessed and was directly used for the determination of aggregate size distribution, preserving the natural structure of the soil aggregates for accurate assessment.

This sampling and preparation protocol ensured consistency in data collection while preserving critical soil characteristics for laboratory evaluation.

3.2 Physical Properties of Soil

3.2.1 Bulk density (BD)

Bulk density (BD) of undisturbed soil was determined in the field using the core-tube method. Soil cores were collected using a cylindrical metal core of known volume. The samples were oven-dried at 105°C for 24 hours to determine the dry weight. Bulk density was then calculated using the following formula:

$$BD (g\ cm^{-3}) = \frac{\text{Weight of oven dry soil in the core (MS,G)}}{\text{Volume of the core (Vt,cm}^3\text{)}} \quad (1)$$

3.2.3 Particle density (PD)

Particle density (PD) of disturbed soil samples was determined using the pycnometer method, following standard laboratory procedures. The calculation was based on the formula:

$$PD (g\ cm^{-3}) = \frac{10}{W_{PW+10} - W_{psw}} \quad (2)$$

Where,

W_{PW} = Weight of water filled in pycnometer
 W_{psw} = Weight of pycnometer + water + soil

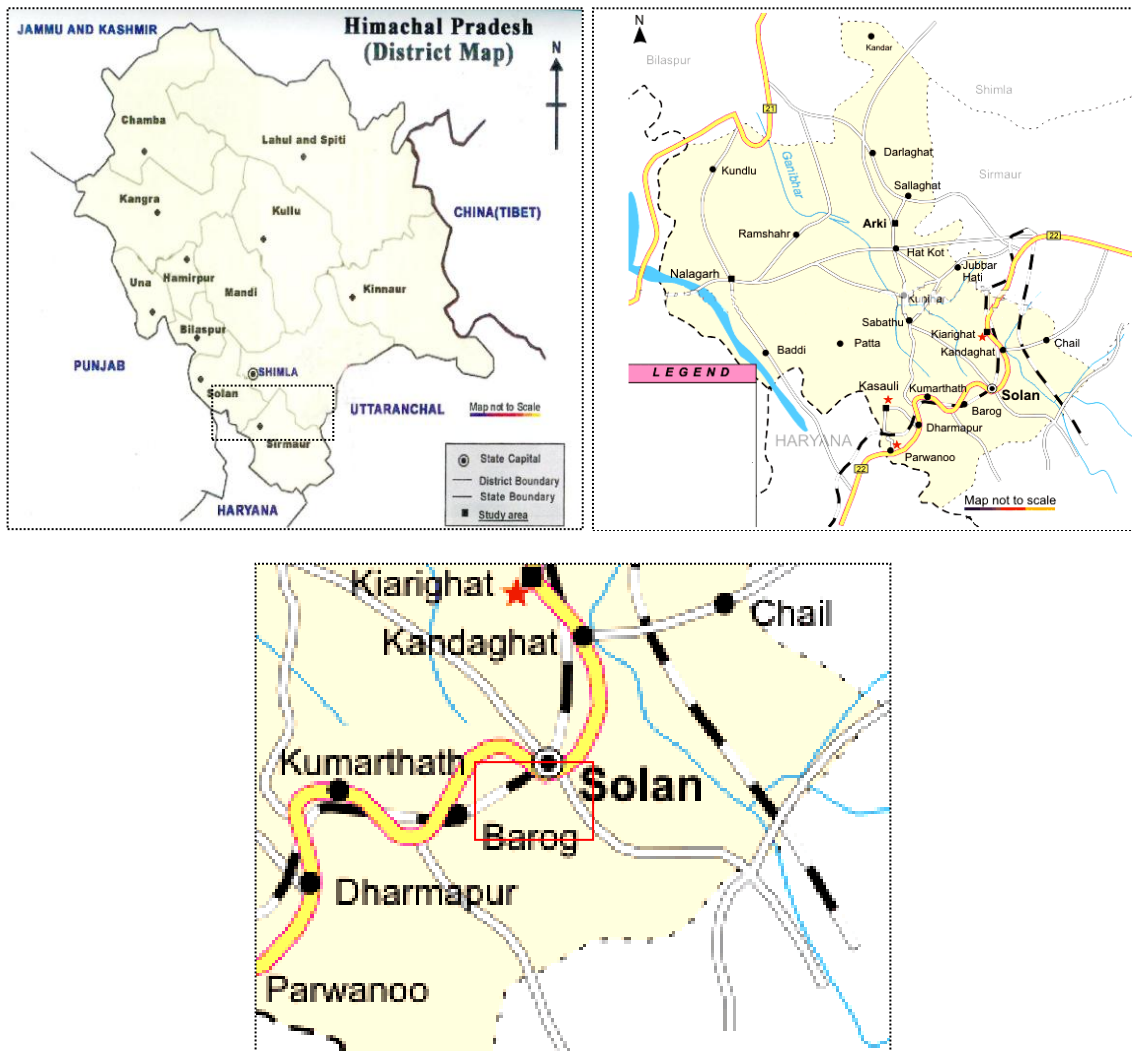


Fig. 1. Map showing study area of watershed Barog-Dhillon located in Solan district of Himachal Pradesh

3.2.3 Porosity

Soil porosity was derived from the values of bulk density and particle density using the following empirical relation:

$$Porosity = 1 - \frac{BD}{PD} \times 100 \quad (3)$$

Where,

BD = Bulk density ($g\ cm^{-3}$)
 PD = Particle density ($g\ cm^{-3}$)

3.3 Aggregate Size Distribution and Mean Weight Diameter (MWD)

Aggregate size distribution was determined through the wet sieving method as described by

Yoder (1936). Water-stable aggregates (WSA) greater than 0.25 mm and less than 0.25 mm in diameter were quantified. The mean weight diameter (MWD), a measure of aggregate stability, was calculated according to the formula by Yonker and McGuiness (1957):

$$MWD = \sum_{i=1}^n d_i W_i \quad (4)$$

Where,

d_i = Mean diameter of each size fraction
 W_i = Proportion of sample size

3.4 Maximum Water Holding Capacity (MWHC)

The maximum water holding capacity of the soil was determined using the Keen Raczowski Box

method, following procedures outlined by Piper, (1966). Samples were saturated, allowed to drain, and weighed to calculate the retained moisture as a percentage of dry soil weight.

3.4.1 Infiltration characteristics

Infiltration characteristics were assessed in the field using double ring infiltrometers installed under each land use type. The rings were installed in duplicate at three randomly selected sites per land use category. Water was added gently to maintain a constant head, avoiding dispersion at the soil surface. Infiltration measurements were recorded for up to 300 minutes, noting the volume of water required to maintain the water level as a function of time.

From the data, both infiltration rate (cm hr^{-1}) and cumulative infiltration (cm) were calculated. The results were plotted separately for each replicate, and average infiltration curves were generated to illustrate trends under different land use systems.

3.5 Statistical Analysis

The statistical analysis of the collected data was carried out using SPSS-18 software. Techniques such as Karl Pearson's correlation coefficient and two-way classification Analysis of Variance (ANOVA) were employed in accordance with the study objectives and the nature of the data.

4. RESULTS AND DISCUSSION

The highest bulk density of both surface and sub-surface soils was recorded under scrub land use, with mean values of 1.57 g cm^{-3} and 1.60 g cm^{-3} in the watershed project area and non-watershed

project area, respectively. In contrast, the lowest bulk density was observed under grassland use, with corresponding values of 1.30 g cm^{-3} and 1.32 g cm^{-3} in the surface and sub-surface soils of the project and non-project areas, respectively.

The data enumerated in Table1 further indicate higher BD values in the lower soil depths compared to upper one. Zhang *et al.*, (2022) reported that increased overburden pressure leads to soil particle rearrangement and compaction in deeper layers. Agricultural practices like tillage and residue incorporation typically affect surface soils, increasing porosity and reducing BD. Furthermore, higher bulk density in scrub land might be due to low clay content and high erodible nature while lowest in grass land might be due to high organic carbon content. Similar results were reported by Gupta *et al.*, (2010) & Goswami (2009). The soil of watershed project area was also significant in respect to bulk density (1.40 and 1.42 g cm^{-3}) as compared to non-project area of watershed (1.44 and 1.46) g cm^{-3} of surface and sub-surface soils, respectively. All the land uses under non project area of watershed showed highest bulk density as compared to project area of watershed that might have occurred due to the decrease in organic matters accumulation in non-project area.

The highest particle density of surface and sub-surface soils was found in scrub land use with mean value of (2.67 and 22.72) g cm^{-3} in watershed project area and non-watershed project area, respectively (Table 2). While, the lowest was found in grassland land use (2.35 and 2.40) g cm^{-3} in surface and sub-surface soils of watershed project area and non-watershed project area, respectively.

Table 1. Bulk density of soil of under different land uses

C	BD (g cm^{-3})					
	Depth (cm)					
L	0-15			15-30		
	WPA	NPA	Mean	WPA	NPA	Mean
Agriculture	1.43	1.47	1.45	1.44	1.48	1.46
Forest	1.35	1.38	1.36	1.37	1.40	1.38
Grassland	1.28	1.32	1.30	1.30	1.34	1.32
Scrub	1.56	1.59	1.57	1.59	1.62	1.60
Mean	1.40	1.44		1.42	1.46	
CD 5%	L : 0.01			L : 0.02		
	C : 0.01			C : 0.01		
	LxC : NS			LxC : NS		

WPA : Watershed Project Area

NPA : Non-Project Area of Watershed

L = Land uses

C = Conditions

Table 2. Particle density of soil of under different land uses

		PD (g cm⁻³)					
		Depth (cm)					
C		0-15			15-30		
L		WPA	NPA	Mean	WPA	NPA	Mean
	Agriculture	2.57	2.60	2.58	2.62	2.65	2.64
	Forest	2.52	2.53	2.52	2.56	2.58	2.57
	Grassland	2.35	2.36	2.35	2.39	2.41	2.40
	Scrub	2.66	2.69	2.67	2.70	2.74	2.72
	Mean	2.52	2.54		2.57	2.60	
	CD 5%	L : 0.03			L : 0.02		
		C : 0.02			C : 0.02		
		LxC : NS			LxC : NS		
		WPA : Watershed Project Area			L = Land uses		
		NPA : Non-Project Area of Watershed			C = Conditions		

Particle density was higher in sub-surface when compared to the surface layer in all the land use which may be ascribed to comparatively higher organic matter content in the surface layers under all the land use. The results are in conformity with the findings documented by Kumar & Singh., (2007). The highest particle density in the scrub land soils might have resulted due higher organic content. Khan *et al.*, (1998) & Kumar *et al.*, (2002) also documented an increased in particle density with the addition of organic matter content. The soil of watershed project area was also significant in respect to particle density (2.52 and 2.57g cm⁻³) as compared to non-project area of watershed (2.54 and 2.60 g cm⁻³) of surface and sub-surface soils, respectively. All the land uses under non project area of watershed showed highest particle density compared to project area of watershed that might have occurred due to the decrease in

organic matters accumulation in non-project area.

The average porosity values recorded highest under forest land use (45.95 and 44.98) per cent in both the soil layers due to more organic matter content such observations were also made by Khan *et al.*, (1998) & Kumar *et al.*, (2005) and lowest in scrub land (39.67 and 38.73) per cent of watershed project area and non-watershed project area, respectively (Table 3).

The soil of watershed project area was also significant in respect to porosity (43.81 and 42.77) per cent as compared to non-project area of watershed (42.46 and 41.22) per cent of surface and sub-surface soils, respectively. All the land uses under project area of watershed showed highest porosity as compared to non-project area of watershed that might have occurred due to the decrease in bulk density and higher organic matters in watershed project area.

Table 3. Porosity of soil of under different land uses

		Porosity (%)					
		Depth (cm)					
C		0-15			15-30		
L		WPA	NPA	Mean	WPA	NPA	Mean
	Agriculture	43.25	42.14	42.69	42.02	40.92	41.47
	Forest	46.40	45.50	45.95	45.55	44.41	44.98
	Grassland	45.50	42.97	44.23	44.37	41.25	42.81
	Scrub	40.09	39.25	39.67	39.15	38.31	38.73
	Mean	43.81	42.46		42.77	41.22	
	CD 5%	L : 1.07			L : 0.98		
		C : 0.75			C : 0.69		
		LxC : NS			LxC : NS		
		WPA : Watershed Project Area			L = Land uses		
		NPA : Non-Project Area of Watershed			C = Conditions		

Table 4. Aggregate size distribution (%) of soils under different land uses

Depth (cm)		0-15						15-30					
Land Uses		>5.0	2.0-5.0	1.0-2.0	0.5-1.0	0.25-0.50	0.10-0.25	>5.0	2.0-5.0	1.0-2.0	0.5-1.0	0.25-0.50	0.10-0.25
Agriculture	WPA	4.50	4.57	8.24	9.05	19.89	52.44	4.44	3.85	7.40	9.18	19.76	54.32
	NPA	4.06	3.57	7.85	9.80	20.35	53.05	4.00	2.86	7.01	9.93	20.22	54.92
Forest	WPA	8.23	8.50	8.85	12.95	17.50	42.32	8.31	10.25	7.35	12.85	16.00	43.04
	NPA	7.97	8.25	8.57	11.65	18.95	43.08	8.05	10.00	7.07	10.65	17.45	43.80
Grassland	WPA	8.13	8.05	9.84	10.75	17.75	43.58	8.27	8.22	9.23	9.85	15.25	44.08
	NPA	7.25	6.78	8.25	11.45	18.94	44.87	7.42	6.95	7.78	10.55	16.27	45.37
Scrub	WPA	2.58	3.26	7.37	9.23	20.73	55.78	2.30	2.98	5.12	8.81	20.57	55.14
	NPA	2.30	3.05	7.23	9.59	19.75	56.85	2.02	2.77	4.98	9.17	19.59	56.21

WPA : Watershed Project Area

NPA : Non-Project Area of Watershed

Table 5. Maximum water holding capacity of soils under different land uses

C	MWHC(%)					
	Depth (cm)					
L	0-15			15-30		
	WPA	NPA	Mean	WPA	NPA	Mean
Agriculture	42.78	41.60	42.19	46.54	45.26	45.90
Forest	45.83	44.68	45.25	46.84	45.69	46.26
Grassland	44.66	42.47	43.56	45.72	43.52	44.62
Scrub	39.57	38.25	38.91	42.09	40.67	41.38
Mean	43.21	41.75		45.30	43.78	
CD 5%	L : 1.25			L : 1.18		
	C : 0.88			C : 0.83		
	LxC : NS			LxC : NS		
	WPA : Watershed Project Area			L = Land uses		
	NPA : Non-Project Area of Watershed			C = Conditions		

The aggregates (>5mm in diameter) had highest distribution percentage in soils under forest land with mean values of (8.23, 7.97 and 8.31, 8.05) per cent of surface and sub-surface soils of watershed project area and non-watershed project area, respectively (Table 4). While, the lowest was found in scrub land use (2.58, 2.30 and 2.30, 2.02) per cent in surface and sub-surface soils of watershed project area and non-watershed project area, respectively.

The highest MWHC of surface and sub-surface soil was found in forest land (45.25 and 46.26) per cent in watershed project area and non-watershed project area, respectively. While, the lowest was found in scrubland land use (38.91 and 41.38) per cent in surface and sub-surface soils of watershed project area and non-watershed project area, respectively (Table 5).

Highest MWHC in forest land soils may be due to more organic carbon content coupled with higher percentage of clay in forest lands which enhanced the available water. These results are in accordance with the findings of Ojeniyi & Dexter, (1984); Kumar *et al.*, (2005); Khongjee, (2012) & Kyndiah, (2012). In the interaction effect, the MWHC of soil for different land uses ranged between (38.25-45.83 and 40.67-46.84)

per cent in surface and sub-surface soils of watershed project and non-watershed project area, respectively. The highest MWHC of soil was recorded in forest land soil (45.83 and 46.84) per cent under watershed project area and lowest in scrub land (38.25 and 40.67) per cent under non project area watershed of surface and sub-surface soils respectively. The soil of watershed project area was also significant in respect to MWHC (43.21 and 45.30) per cent as compared to non-project area of watershed (41.75 and 43.78) per cent of surface and sub-surface soils, respectively. Similar observations were also made by Gupta *et al.*, (2010). Higher value of MWHC may be due to less bulk density and more organic carbon content present in watershed project area as compared to non-project area of watershed.

The highest infiltration rate was found in forest land use (9.1 and 6.6) cm hr⁻¹ and while the lowest infiltration rate was found in scrub land use (2.8 and 2.0) cm hr⁻¹. Whereas, highest cumulative interest rate was found in forest land use (45.8 and 33.0) cm and lowest cumulative interest rate was found to be in scrub land use (14.00 and 10.20) cm in watershed and non-watershed project area, respectively (Table 6).

Table 6. Cumulative infiltration and infiltration rate characteristics of soil under different land uses

Land uses	Cumulative infiltration (cm)		Infiltration rate (cm hr ⁻¹)	
	WPA	NPA	WPA	NPA
Agriculture	33.5	22.6	6.7	4.5
Forest	45.8	33.0	9.1	6.6
Grassland	36.0	26.0	7.2	5.2
Scrub	14.0	10.2	2.8	2.0
Mean	32.32	22.95	6.45	4.57
	WPA: Watershed Project Area		NPA : Non-Project Area of Watershed	

High organic matter content, good soil aggregations of forest land might be responsible for higher infiltration rate in forest land. Chu *et al.*, (2024) & Marthur *et al.*, (1982) also studied the role of vegetation in improving the infiltration characteristics. Higher value of infiltration rate under watershed project area may be due to increase in organic matters accumulation because of watershed project activities. Mathan & Mahendran, 1994 also observed that forest land under watershed project area was well aggregated resulting into higher infiltration, less detachment and less migration of soil particles through runoff. All the land uses showed the abrupt decline in the infiltration rate with time and became more or less steady after 100 minutes. On the basis of infiltration rate, the different land uses followed the trend:

Forest lands > Grasslands > Agricultural lands > Scrub land

5. SUMMARY AND CONCLUSION

The present study on “Assessment of Soil Physical Properties of Barog Dhillon Watershed in Solan District of Himachal Pradesh Under Different Land Uses” clearly highlights the significant influence of land use and watershed management practices on the physical condition of soils. The comparative assessment between watershed project areas and non-project areas revealed that soils in the project areas consistently exhibited superior physical properties, including lower bulk density, higher porosity, improved aggregate stability, greater water holding capacity, and enhanced infiltration rates. Among the various land use types, forest and grasslands demonstrated the most favourable soil physical properties, primarily due to higher organic matter input, better vegetation cover, and reduced human-induced disturbance. In contrast, scrublands exhibited the poorest soil conditions, marked by high bulk density, low porosity, weak aggregate structure, and minimal infiltration capacity—indicative of degradation and low soil productivity. The study confirms that sustainable land management practices, particularly under watershed development initiatives, play a crucial role in maintaining and improving soil physical health. It also underscores the need for soil conservation, afforestation, and regulated land use planning in hilly terrains like the mid-Himalayan region to mitigate erosion, enhance water retention,

and support long-term agricultural productivity.

6. RECOMMENDATIONS

Based on the study of soil physical properties in the Barog Dhillon Watershed, farmers are advised to adopt agroforestry and maintain grassed buffer zones to enhance soil structure. Conservation tillage should be practiced to reduce compaction and improve water infiltration. Regular use of organic amendments like FYM and compost is essential to maintain porosity and soil moisture. Soil and water conservation structures such as check dams and contour bunds are recommended on sloping lands. Lastly, community-based watershed management should be promoted for collective and sustainable land use.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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