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ORIGINAL ARTICLE
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Assessment of infiltration rate and soil physical properties in different forest types in Kempty watershed at Garhwal Himalaya of Uttarakhand

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ABSTRACT

Studying the changes in soil qualities induced by diverse land uses enables steps to be implemented that limit the risk of future harmful consequences. This study aimed to assess soil physical attributes and infiltration rates for various types of forest land uses in a Kempty watershed of the Garhwal Himalaya. The land use types selected were oak forest (OF), pine forest (PF), and mixed forest (MF). A sample survey was conducted in 40 (10 × 10 m) quadrats to collect soil samples and measure infiltration rates for each forest type. Soil samples were collected from 0-30 cm depths, and soil bulk density, organic carbon, texture, and moisture were analysed. Our findings revealed that OF had higher bulk density (BD) (1.28 ± 0.08 gm cm^3), organic carbon (OC) (30.63 ± 0.82 mg kg^{-1}), and soil moisture content (37.37 ± 1.35 %) than PF and MF. Infiltration rates (IR) were considerably higher (4.23 ± 0.17 cm hr^{-1}) in OF compared to PF (3.37 ± 0.23cm hr^{-1}) and MF (3.74 ± 0.18 cm hr^{-1}). Although the infiltration rate in the MF was statistically at par with the OF, PF had the lowest infiltration rates. The higher BD was observed during the summer and OC during the winter. The higher IR (9.29 ± 0.28 cm hr^{-1}) was observed during May. Higher soil characteristics and infiltration rates in OF may be linked to the accumulation of more leaf litter on the forest floor and a higher decomposition rate than in PF and MF.

***Key words:**
Forest soil
Hydraulic properties
Soil permeability
Soil texture
Water retention

HIGHLIGHTS

- The hydraulic attributes are determined by spatial arrangement of soil particles.
- The soil properties were improved under oak forest than pine and mixed forests.
- Infiltration was also considerably higher in oak forests compared to other forests.
- Improved soil properties in oak forests may be linked to the accumulation of more leaf litter.

1 | INTRODUCTION

In northern India, the Garhwal Himalaya is a distinctive natural sphere with a wide range of landscapes and abundant wildlife. The importance of soil in maintaining this ecosystem's delicate equilibrium among its towering peaks and dense flora cannot be emphasized. Forests significantly influence the physical and hydrological characteristics of the soil, which is a key feature of the Garhwal Himalaya.

Water enters into the soil at a rate known as the infiltration rate, which is a crucial sign of soil health. It directly impacts surface runoff, groundwater recharge, and plant growth (Kumar *et al.,* 2020). The complex interactions between the physical characteristics of soil and forest land use greatly influence the hydrological dynamics of the area. For efficient land management, conservation, and sustainable resource use, it is necessary to understand these linkages. The hydraulic attributes of the soil are defined by its texture and the spatial distribution of particles and gaps (Dinesh *et al.,* 2022). Although texture is considered a static property, structure can change dynamically across both space and time based on soil type and management practices. Because of the dynamic nature of the soil structure, estimating infiltration is a difficult process. However, the living and decaying roots of diverse trees and forests create a network of interlinked channels in the soil known as macropores. Flow via these macropores can occur hundreds of times faster than through the soil matrix (dos Santos *et al.,* 2018). Furthermore, organic material from leaf litter and tree roots enhances soil structure, which may increase infiltration rates. Humus, organic glues formed by fungus and bacteria decomposing organic materials, and polymers and sugars released by roots contribute to better soil structure (Kaushal *et al.,* 2021). Trees generate more stable macropores. As a result, infiltration rates are higher in tree-covered areas than in unforested ones. Furthermore, the lining found on the roots of woody plants contributes to the stability of the macropores even after the root decays.

The land use patterns of Garhwal Himalaya have shifted, with forests playing an essential role in the region's socioeconomic and ecological integrity. Rapid urbanization, agricultural expansion, and changes in forest management practices have prompted concerns about soil resilience in the face of changing land uses (Lal, 2012). This study aims to assess the infiltration rate and important physical soil qualities across various forest land uses to understand better the complex dynamics of soil that shape the Garhwal Himalayan landscape.

The study seeks to quantify and evaluate the infiltration rates of diverse forest land uses. Soil texture and composition have a significant impact on water retention and drainage. This study will look into the physical characteristics of soil, namely distribution of particle size, organic matter concentration, bulk density, and porosity (Liansangpuii *et al.,* 2019). The objective of this research is to connect land use, soil characteristics, and hydrological processes by comparing infiltration rates to physical soil attributes. This information is critical for anticipating water supply, minimizing erosion concerns, and maintaining the fragile ecosystem of the Himalaya. The outcomes of this research will provide significant perspectives for conservation and land management initiatives.

Understanding how different forest land uses impact soil health is essential for creating sustainable practices that support the long-term health of the Garhwal Himalayan ecosystem. Due to its ecological sensitivity and socioeconomic significance, the Garhwal Himalaya is an important geographic area for research to understand the complex dynamics of land use and its effects on soil health. This research has the potential to provide valuable insights for policymakers, land managers, and conservationists, supporting initiatives that balance human activity with the biological integrity of this pristine Himalayan region.

2 | MATERIALS AND METHODS

2.1 | Study Area

The present study was carried out in the Kempty watershed. The Kempty watershed is situated in Mussoorie Forest Division in the Dehradun district of Uttarakhand. The nomenclature of the Kempty micro-watershed is 2C7A5h4 according to the Uttarakhand micro watershed atlas. It is located between latitude N 30°28.013´ to 30°28.538´ and longitude E 78°1.501´ to E78°2.307´ with an average elevation of 1662 m. The area of the watershed is 870 ha. The mountainous range of this watershed is from 1410 m to 2273 m above mean sea level. The watershed is inhabited by *Pinus roxburghii* forest and *Quercus leucotrichophora* forest and comes under Himalayan temperate forest (Champion and Seth, 1968). In spite of this, there are still other tree species found in the forests, including *Toona serrate, Pyrus oblongum, Myrica esculenta, Daphniphyllum himalayense, Quercus leucotrichophora, Quercus floribunda, Pinus roxburghii,* and *Pinus wallichiana*. The distribution of vegetation in the Kempty watershed is organised by varying microenvironments, particularly moisture and temperature, along the altitudinal-height. The Himalayan moist temperate forest of Oak (*Quercus leucotrichophora* A. Camus ex Bahadur) and Chir pine (*Pinus roxburghii* Sarg.) thrives up to 1400 to 2200 m as a pure forest of *Quercus leucotrichophora* A. Camus ex Bahadur and *Pinus roxburghii* Sarg and or as a mixed forest with some other scattered species. Prior to the data collection, the watershed's forest was surveyed. According to the survey, the watershed is home to three different types of forests: mixed forests (MF), *P. roxburghii* forests (PF), and *Q. leucotricophora* forests (OF) (Kumar *et al.,* 2021).

2.2 | Climate and Soil

The Kempty Watershed has a subtropical to temperate climate with mean annual precipitation of 1,250 mm and annual precipitation ranging from 850 mm to 2,200 mm. Within the watershed, the average yearly maximum air temperature ranged from 25.1 to 26.8 °C, while the average yearly minimum temperature varied from 7.2 to 10.3 °C. The average yearly air temperature, however, fluctuated from 16 to 18 °C. The Kempty region's soils are mostly influenced by tall vegetation and are formed from alluvial, medium-to-moderately coarse-textured materials.

2.3 | Sampling and Analysis

Stratified random sampling was used to gather samples on the basis of the seasons-rainy, winter, and summer. Based on the watershed's structure, we divided the watershed into three separate categories: the lower one, where *Q. leucotricophora* was the dominant species; the upper, where *P. roxburghii* was the dominant species; and the middle level, which had mixed forests.

Randomly, we set 40 (10 × 10 m) quadrates in each stratum to collect the samples. Soil samples were collected from each 40 (10 × 10 m) quadrates, then 10 quadrates were composited to make one replication (total of 4 replications). The soil samples were kept in a polybag, air-dried, and processed for further analysis in the laboratory.

Bulk density was determined by using a 10.3 cm diameter core sampler (Blake and Hartge, 1986); soil samples were taken using a core sampler from 4 places (considering four replications) randomly from each stratum to calculate the bulk density. The soil's bulk density was calculated using the BD = W/V formula and was expressed in the unit of g/cm^3. Where BD is bulk density, w is the weight of oven-dry soil (gm), and v is the volume of soil core (cc). The organic carbon content (%) in soil was determined by following the modified Walkley and Black (1934) method. This method involved taking a 1 g soil sample and placing it in conical flasks. Then, 10 ml of $K_2Cr_2O_7$ reagent and 20 ml of H_2SO_4 were added to the flask. The samples were titrated against ferrous ammonium sulphate after adding 200 ml of distilled water. The particle size analysis is used to determine the relative percentage of sand, silt and clay by the Bouycous hydrometer method (Bouyoucus, 1962). 50 g of soil was put in flaks with distilled water, and the soil was heated in a water bath with additions of sodium hexameta-phosphate and hydrogen peroxide separately over a time period until all of the organic matter was removed. Following this procedure, the samples were transferred into a 1000 ml cylindrical flask, with distill water added to increase the capacity to 1000 ml. A hydrometer plunger was used to take the readings. The soil moisture (%) was measured using the pro check sensor and logger at monthly intervals.

2.3.1 | Infiltration rate

Using a small disc infiltrometer, the soil infiltration was determined for each of the three forest land uses that were chosen for the study (Dohnal *et al.,* 2010). At time zero, the infiltrometer was positioned on the soil's surface to establish firm contact with it. In the record sheet, the amount of water that permeated the soil was noted as a function of time. Using a 2 cm suction headset in the infiltrometer, the process was carried out. For every observation, the amount of water (mL) that seeps into the soil at different times (in min) throughout a one-hour period is calculated. The macro sheet was used to determine the square root of time and cumulative infiltration (in cms). After that, the data is fitted to Zhang's (1997) equation (eq. 1) to calculate the infiltration rate of soil, yielding the following values for constants C1 and C2.

$$I = C_1 t + C_2 \sqrt{t} \quad \text{... (1)}$$

Where t (min) is the time and I is the cumulative infiltrability (cm). The following equation is now used to calculate the soil's infiltration rate:

$$K = \frac{C2}{A} \quad \text{...(2)}$$

Where A is the value which relates the suction rate and radius of the infiltrometer disk to the van Genuchten parameters for a particular soil type, and $C2$ is the slope of the cumulative infiltration curve vs the square root of time.

$$A = \frac{11.65\,(n^{0.01}-1)\,\exp[2.92(n-1.9)ah_0]}{(ar_0)^{0.91}} \quad n \geq 1.9 \quad \text{...(3)}$$

$$A = \frac{11.65\,(n^{0.01}-1)\,\exp[7.5(n-1.9)ah_0]}{(ar_0)^{0.91}} \quad n \geq 1.9 \quad \text{...(4)}$$

Where n and α are the van Genuchten parameters for the soil (Carsel and Parrish, 1988), r_0 is the disk radius, and h_0 is the suction at the disk surface.

2.4 | Statistical Analysis

The difference of all soil parameters and infiltration rate was assessed by two-way analysis of variance (ANOVA). Comparisons among the different seasons and forest land uses were made with the turkey post hoc test at the significant difference ($p<0.05$). All the data was subjected to analysis by the R statistical software.

3 | RESULTS AND DISCUSSION

3.1 | Soil Properties

The bulk density (Fig. 1) at 0-30 cm soil depth was significantly higher in summer (1.42±0.008 g cm^{-3}) and lowest in the winter season (1.39±0.01 g cm^{-3}), which was statistically at par with rainy (1.38±0.007 g cm^{-3}) season. Among the land uses, the higher bulk density (Table 1) was recorded in a pine forest (PF) (1.37±0.03 g cm^{-3}), mixed forest (MF) (1.31±0.04 g cm^{-3}), which was statistically at par with oak forest (OF), (1.28±0.04 g cm^{3}). The organic carbon (OC %) at 0-30 cm soil depth was significantly ($F=57.38$, $p<0.0001$) higher (Fig. 2) in winter season (2.97±0.31) and decreased

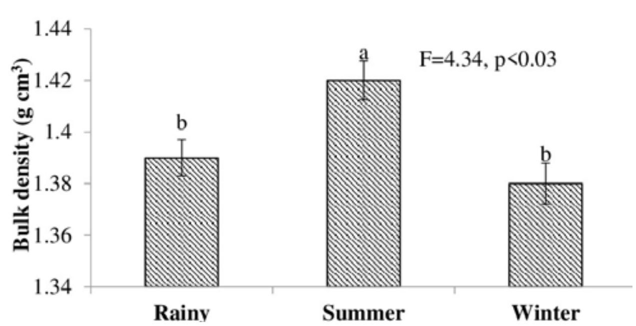


FIGURE 1 Bulk density during different seasons

TABLE 1 Soil properties and infiltration rate under forest land uses

Land use	Bulk Density (g cm^{-3})	Organic Carbon (%)	Soil Moisture (%)	Infiltration rate (cm hr^{-1})
OF	1.28^{b}±0.08	3.06^{a}±0.79	37.37^{a}±1.35	4.23^{a}±0.17
PF	1.37^{a}±0.15	2.68^{c}±1.02	35.51^{c}±1.33	3.37^{b}±0.23
MF	1.31^{b}±0.12	2.77^{b}±0.81	36.23^{b}±1.41	3.74^{b}±0.18
P-value	P<0.001	P<0.0001	P<0.001	P<0.001
F-value	210.74	91.61	25.57	234.54

OF = Oak Forest, PF = Pine Forest, MF = Mixed Forest

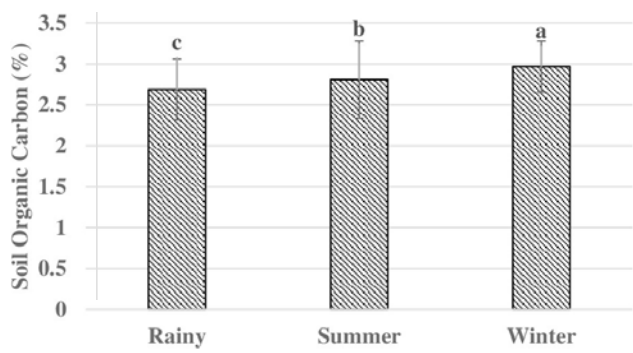
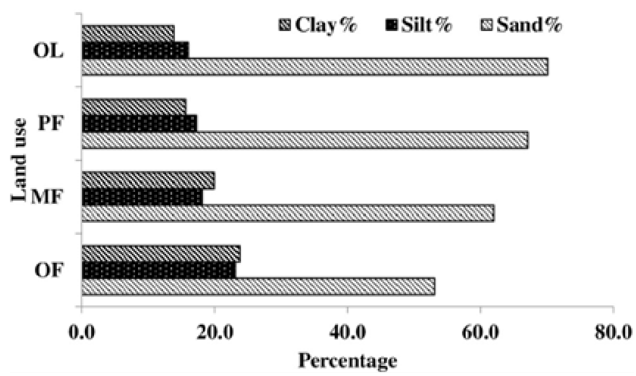


FIGURE 2 Soil organic carbon at 0-30 cm soil depth during different seasons



OL= Open Land, PF = Pine Forest, MF = Mixed Forest, OF = Oak Forest

FIGURE 3 Soil texture (particle distribution analysis) of different forest land uses

in summer (2.81±0.47) and rainy (2.69±0.37) season. Among different forest land uses (Table 1), significantly (F=591.61, p<0.001) higher OC was observed in OF (3.06±0.39) and decreased in MF (2.77±0.31), and PF (2.68±0.24). The interaction (Table 2) between seasons and land use types on OC was insignificant (p=0.58). The higher OC was recorded in OF (3.14±0.27) during the winter season and lower in PF (2.54±0.18) during rainy season.

The texture of different land use varied (Fig. 3) in the fractions of soil particles that include clay, silt, and sand. The percentage of sand varied in various land uses from 53.08 to 70.15%, while the percentage of silt and clay varied from 16.02 to 23.12% and 13.83 to 23.08%, respectively. The highest clay (23.12) and silt (23.08%) percentages were observed in OF, while it consists of the lowest sand (53.08%) percentage. Under MF, the percentage of sand (62.02), silt (18.08), and clay (19.9) was higher than that of the OF. However, under PF and open land (OL), the proportion of sand increased slightly compared to OF and MF. Among the forest land uses (Table 1) the significantly (F=25.57, p< 0.0001) higher soil moisture (%) was recorded in OF (37.37 ± 1.35) followed by MF (36.23 ± 1.44) and PF (35.51 ± 1.33). The soil moisture content significantly (F = 647.25, p < 0.0001) differed during all the months at 0-30 cm soil depth. The highest soil moisture (Table 3) was recorded in July month (46.99 ± 0.36), which was statistically at par with August (46.21 ± 0.83). It decreased in Jan (41.00 ± 0.95), which was statistically at par in Feb (40.49 ± 2.02) and Sept (39.63 ± 0.61). The lowest soil moisture was measured in May (22.63 ± 0.62). The interaction between months and forest land uses (Table 4) on soil moisture levels

TABLE 2 Interaction between seasons and forest land uses for organic carbon (%) at 30 cm soil depth

	Rainy	Winter	Summer
OF	2.89±0.25	3.14±0.24	3.04±0.27
PF	2.54±0.18	2.85±0.29	2.65±0.24
MF	2.64±0.21	2.92±0.27	2.74.±0.31
F=0.67, p=0.66			

OF = Oak Forest, PF = Pine Forest, MF = Mixed Forest

TABLE 3 Infiltration rate and soil moisture content during different months

	Infiltration rate (cm hr^{-1})	Soil moisture (%)
Aug	-	46.21^{a}±0.83
Sep	2.58^{e}±0.19	39.63^{b}±0.61
Oct	3.02^{d}±0.16	37.15^{c}±0.45
Nov	2.86^{e}±0.12	37.44^{c}±1.04
Dec	2.17^{e}±0.08	40.19^{c}±0.70
Jan	2.10^{e}±0.08	41.00^{b}±0.95
Feb	3.07^{d}±0.11	40.49^{b}±2.02
Mar	3.85^{c}±0.12	30.75^{d}±0.33
Apr	5.71^{b}±0.25	23.14^{e}±0.58
May	9.29^{a}±0.28	22.63^{f}±0.62
Jun	5.21^{b}±0.16	30.83^{d}±0.67
July	-	46.99^{a}±0.36
	F = 731.38, p<0.0001	F = 647.25, p<0.0001

TABLE 4 Interaction between months and forest land uses on soil moisture (%) at 0-30 soil depth

	OF	PF	MF
Aug	48.36±0.44	43.24±0.63	47.02±0.77
Sep	41.25±0.17	37.35±0.12	40.28±0.52
Oct	37.32±0.52	35.76±0.19	38.36±0.60
Nov	41.37±0.11	36.46±0.30	34.48±0.43
Dec	42.04±1.07	40.28±0.90	38.24±0.54
Jan	44.38±0.14	38.35±0.78	40.26±0.84
Feb	32.54±0.83	44.24±0.87	44.68±0.44
Mar	31.04±0.52	31.06±0.60	30.14±0.61
Apr	25.08±0.10	23.08±0.59	21.25±0.15
May	23.68±0.57	20.28±0.21	23.92±0.21
Jun	33.24±0.48	29.42±0.56	29.84±0.67
Jul	48.16±0.33	46.56±0.53	46.25±0.36
F = 27.34, p<0.0001			

OF = Oak Forest, PF = Pine Forest, MF = Mixed Forest

TABLE 5 Interaction between months and forest land uses on infiltration rate (cm hr^{-1})

	OF	PF	MF
Sep	3.08±0.23	2.02±0.30	2.64±0.06
Oct	3.47±0.24	2.56±0.22	3.02±0.01
Nov	3.22±0.15	2.48±0.14	2.87±0.06
Dec	2.32±0.14	2.03±0.17	2.16±0.05
Jan	2.28±0.13	1.96±0.16	2.06±0.03
Feb	3.37±0.19	2.86±0.15	2.98±0.05
Mar	4.24±0.10	3.47±0.07	3.85±0.06
Apr	6.68±0.17	5.08±0.16	5.38±0.04
May	10.26±0.11	8.34±0.09	9.28±0.10
Jun	5.76±0.13	4.84±0.15	5.02±0.13
F=4.04, p<0.0001			

OF = Oak Forest, PF = Pine Forest, MF = Mixed Forest

at 0-30 cm depth were significantly higher (F = 27.34, p < 0.0001). The maximum soil moisture was found in OF (48.16 ± 0.33) during July month and lowest in PF (20.28 ± 0.21) during May month.

The bulk density was found to be higher in the summer season as compared to rainy and winter seasons. The addition of carbon to the soil has a direct relationship with bulk density. So, the decreased bulk density during the winter could be due to increased soil carbon. However, the higher bulk density was responsible for less carbon addition in the rainy and summer seasons. The addition of soil carbon decreases the bulk density. The lower bulk density under oak forest (OF) than others was also due to the addition of more carbon in the soil. The present study's findings depicted the inverse relationship between soil bulk density and soil organic carbon content, which has been reported by several investigators (Gupta and Sharma, 2011). It was also reported by Nayak *et al*. (2009) that the soil bulk density under the *Prosopis juliflora* tree was significantly lower than that of the open area. The soil texture regarding sand, silt and clay percentage was recorded in all forest land uses. A higher clay percentage was observed in oak forests than in MF, PF, and OL. The production of high litter falls on the forest floor, and higher soil moisture in the Oak forest leads to enhanced litter decomposition rate and addition of organic matter in the soil. The higher sand percentage overall in land use indicates the coarse texture of the soil in this region, which is also reported by Kumar *et al.* (2020). Common seasonal variation persisted in all three forest land uses, suggesting that climatic variables could have been vital in controlling variation in soil carbon pools. The slow decomposition rate may explain why forest land usage has the highest soil organic carbon and total carbon during the winter season. Lower temperatures throughout the winter are known to delay the decomposition rate by inhibiting biological activity (e.g., enzymes, bacteria, and insects).

Soil microbes slow down the decomposition of litter and biomass, which results in reduced carbon losses as CO_2 from the soil through microbial respiration. A large portion of the original carbon remains in the soil during the winter (Kaushal *et al.,* 2020; Kumar *et al.,* 2020). However, in the warmer seasons, including summer and autumn, the higher rate of decomposition by soil microbes results in a high amount of carbon loss from the soil due to microbial respiration, although a small proportion of the original carbon remains in the soil. The build-up of soil organic was higher in OF and MF than PF due to differences in root intensity and biomass and different decomposition rates in these forest land uses. Our results conform to the results of Kaushal *et al.* (2020). They reported that the build-up of soil organic matter and nutrient turnover is affected by the input of nutrients through leaf, stem, branch and root Lalitha *et al.,* 2019.

3.2 | Infiltration Rate

Among the forest land uses, the significantly higher infiltration rate (Table 1) was recorded in OF (4.23±0.42 cm hr^{-1}) followed by MF (3.74±0.36 cm hr^{-1}), which was at par with PF (3.37±0.34 cm hr^{-1}). The significantly higher infiltration rate (Table 3) was observed in May (9.29±0.28 cm hr^{-1}) month and decreased in April (5.71±0.25 cm hr^{-1}), which was statistically at par in June (5.21±0.16 cm hr^{-1}) and then further decreased in March (3.85±0.12 cm hr^{-1}) and October (3.02±0.16 cm hr^{-1}) which was statistically at par in February (3.07±0.11 cm hr^{-1}). The lower infiltration was recorded in Jan (2.10±0.08 cm hr^{-1}), which was statistically at par in Dec (2.17±0.08 cm hr^{-1}), Sept (2.58±0.19 cm hr^{-1}) and Nov (2.86±0.12 cm hr^{-1}). The interaction (Table 4) between months and forest land uses on soil infiltration rate was significant (F=4.04, p<0.0001). The highest infiltration rate was recorded in OF (10.26±0.11 cm hr^{-1}) during May month and the lowest in PF (1.96±0.16 cm hr^{-1}) during Jan.

The present study's findings showed that a higher infiltration rate was recorded during the summer months (May). It might be due to the lower soil moisture during this period. The infiltration of water into the soil rises when the moisture content of the soil decrease. Increased soil moisture content can cause the clay particles to swell more, which lowers the levels of soil pore and hydraulic gradient (Fischer *et al.,* 2014). Energy and mass transport processes control the dynamics of soil water infiltration, and the creation of mass and energy gradients depends critically on the initial moisture content of the soil. As soil moisture increases, the hydraulic gradient decreases, reducing the driving force for water infiltration into the soil. As a result, soil infiltrability can be considered a characteristic of soil that is influenced by its initial water content. However, it is also affected by various factors, including soil texture, structure, mineral composition, and moisture levels throughout the soil profile. These factors can influence the infiltration process by encouraging the formation of soil surfaces as a result of physical compaction and physicochemical dispersion processes caused by raindrop impact during rainfall. Among forest land uses, OF showed the highest infiltration rate compared to MF and PF. This might be attributed to the enhanced carbon content, reduced soil compaction, and increased understory vegetation. Wu *et al.* (2016) reported similar results.

The presence of plants has been observed to improve soil infiltration. They also determined that high-density root systems and root canals improved soil infiltrability by enhancing the soil matrix water infiltration capacity. When compared to other forest types, oak and mixed forests have higher infiltration potential. These differences can be explained by the fact that litterfall and carbon addition rates were higher in oak and mixed forests, which promotes higher porosity and soil permeability, enhancing infiltration. These forests also have a large root system, which has increased the potential for infiltration.

4 | CONCLUSIONS

The findings revealed that oak forests exhibited higher bulk density and OC levels compared to mixed and pine. The increased BD and OC increase the porosity of soil in oak forests, and as a result, the infiltration rate is higher in oak forest than in pine and mixed forests. So, our data show that the oak forest significantly impacted soil infiltration rate. Oak forests are significantly influenced by increased litter on the forest floor and the addition of OC; similarly, roots impact soil infiltration, concluding that "woody roots can boost infiltration quite rapidly, allowing water to move across root channels along existing live roots." However, more research is required to validate the findings more effectively.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the results of this study are available within the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR'S CONTRIBUTION

AK: Data curation, writing original draft, visualization and investigation. PK and HS: Supervision, conceptualization. NK, SB and NSK: Reviewing and Editing, formal data Analysis.

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