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Assessment of soil physicochemical properties along the altitudinal gradients in Sindh forest range, India

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Abstract
The present study was carried out to evaluate the physicochemical properties of soil along the altitudinal gradients of Sindh forest range in the Ganderbal District, J & K, India. 81 soil samples were drawn from three different altitudes: The lower A1 (1800-2200 m amsl), middle A2 (2200-2600 m amsl), and upper A3 (>3000 m amsl) from 0-30 cm depth. In terms of pH, the soil was slightly acidic in the A2 (5.97) and moderately acidic in both A1 (6.43) and A3 (6.22). Electrical conductivity was recorded highest in A1 (0.35 dSm-1) followed by A3 (0.31 dSm-1) and A2 (0.27 dSm-1). Bulk density showed a significant positive correlation with clay (r = 0.42, *P*<0.01). The highest recorded bulk density was recorded in A1 (1.41 g/cm-3) followed by A3 (1.32 g/cm-3) and A2 (1.27 g/cm-3). The maximum value for soil moisture was recorded in A2 (27.64%) followed by A3 (25.28%) and A1 (21.53%). The texture class of soil was loam for A1, silt loam for A2, and silt loam for A3. The organic carbon was highest in A2 (1.68%) followed by A3 (1.41%) and the minimum for the A1 (1.22%). Sand showed significant negative correlation with altitude (r = 0.455, *P*<0.01) and silt (r = 0.713, *P*<0.05). Silt showed a significant positive correlation with organic carbon (r = 0.497, *P*<0.05) and a strong negative and significant correlation with clay (r =-0.767, *P*<0.05). Organic carbon showed a negative and significant correlation with pH (r =-0.632) and EC (r =-0.630) However, organic carbon showed a positive significant correlation with both soil moisture (r =0.533, *P*<0.05). Soil moisture exhibited a significant negative correlation with pH (r = 0.575, *P*<0.05). The present study concludes that soil physicochemical properties in a coniferous forest of Sindh forest range in the Ganderbal district of Jammu and Kashmir show variation with altitude.

Keywords: Physicochemical properties, temperate soil, upper Indus basin, forests, organic carbon, western Himalayan region

1. Introduction

In complex systems like soils, climate and nutrients play a major role as climatic factors influence differences in vegetation and soil composition whereas organic matter, soil microbes, and minerals act as a medium for the growth of terrestrial plants on the earth's surface. These factors are responsible for different physical and chemical characteristics of soil and eventually have an impact on soil quality and soil fertility (Jha *et al*. 1984) [14]. Various factors, such as the physical and chemical characteristics of the soil, its texture, its structure, the availability of nutrients, the amount of soil water that is accessible and its depth, have a significant impact on soil quality and soil fertility (Hanks & Ritchie, 1991) [10]. The stability of soil's physicochemical properties is also crucial for the sustainability of ecosystems as the physical properties of the soil depend upon the shape, structure, size, pore spaces, organic matter, and mineral composition of soil. The chemical properties of the soil are the interactions of various chemical constituents among soil particles and the soil solution. These physicochemical characteristics include soil texture, bulk density, soil structure, soil moisture, soil color, pH, electrical conductivity, cation exchange capacity, organic carbon, organic matter, and soil nutrients. Understanding the specific characteristics of each soil is necessary when dealing with a certain soil, understanding its physical and chemical qualities assists in resource management (N. Brady and R. Weil, 2002) [22]. Different parts of the world have a wide range of physicochemical characteristics. As the altitude gradually increases, bulk density, pH, exchangeable sodium percent and fine silt-sized particles decrease significantly, while organic matter and coarse sand-sized particles increase significantly (Badía *et al*. 2016) [3]. Therefore, assessment of physical and chemical characteristics of soil is used to determine the potential status of nutrients in soils (Wondsen and Sheleme, 2011) [32].

The lapse rate causes the temperature to decrease as we move towards higher altitudes in the Earth's atmosphere. (6.5 C for every 1000 m increase in height). Through fluctuations in precipitation and temperature, altitude influences, not just a vegetation gradient but also physicochemical changes in the soil. So, as (Schinner, 1982) [87] noted, variations in plant and soil composition as well as climate conditions may contribute to the decreased soil microbial activity observed with elevation. Altitude influences not only the variation in the type of vegetation but also physicochemical changes in the soil as it can alter precipitation patterns and cause changes in temperature and pressure. (Schinner, 1982) [87] noted that variations in plant and soil composition as well as climate conditions may contribute to the decreased soil microbial activity observed with elevation. Altitude is frequently used to study the impacts of climatic factors on the dynamics of soil organic matter which determines the level of decomposition of the organic matter (Townsend *et al*. 1995, Lemenih and Itanna 2004) [1, 20]. The changes in altitudinal gradients affect soil organic matter via regulating species variation, soil water balance, soil erosion, deposition mechanisms, and biomass production. (Tan *et al*. 2004) [34] One of the major carbon (C) reservoirs is soil, and it is estimated to hold 1500 Pg (1 petagram is 1015 g), which is more C than is now found in both the atmosphere and vegetation (Boulmane *et al*., 2010; Lehmann and Kleber, 2015) [6]. The most effective setups for examining the impacts of the climate on soil characteristics and making predictions about the impact of climate change on forest soils are altitudinal gradients. Himalayan forests are crucial for regulating climate cooling, soil conservation and buffering up enormous soil nutrient reserves (Sharma *et al*. 2010) [28]. Coniferous temperate soils in temperature-limited situations are currently receiving increased attention as a result of their heightened sensitivity to climate change and accelerated warming potential relative to soils at other latitudes (IPCC, 2013) [12]. Assessment of physicochemical properties of soils along the altitudinal gradients has been studied by various authors in various parts of India and across the world including (Reese and Moorhead 1996; Badía *et al*., (2016) [26, 3]; Bayranvand *et al.*, 2021; Charan *et al.*, 2013) [5, 7]. In general, a reduction in temperature and an increase in precipitation are seen with increasing altitude. Thus, assessing the influences of altitude variability on physicochemical properties is essential for addressing the issue of climate change and productivity levels of forest soils. Such research might produce essential insights into the ecosystems of the Himalayas and the possible impacts of climate change on them. It is vital to establish a soil property baseline with altitude in order to comprehend these distinctive ecosystems and build and implement effective conservation strategies. Therefore, this study aimed to assess the physicochemical characteristics of soils in relation to altitude.

2. Materials and Methods

2.1 Study location and sampling site

The present study was carried out to analyze soil physicochemical properties at three different altitudes in the Sindh forest range which is a part of Sindh forest division Ganderbal, Jammu and Kashmir. The total area of Sindh forest range is 81099.76 ha. Sindh river is the main stream flowing through the division. The area lies between 74°52'40.104"E longitude and 34°15'39.852"N latitude. Three sites were selected based on altitude and were classified as lower (A1), middle (A2) and upper (A3) (Table 1). The study area is part of the Western Himalayan region with temperate and humid conditions as per the agro-ecological sub-region classification of ICAR. The study area is having a hilly terrain and both broadleaved and coniferous forests are present.

2.2 Soil physical properties: The International Pipette Method (Piper, 1966) was used to determine the soil texture. Textural classes were determined by using USDA textural triangle for the determination of textural classes. Bulk density was determined with the help of the Standard core method (Wild *et al*., 1979) [31]. Using a core sampler water content of the soil was determined by obtaining the weight of the wet core, then drying it in an oven at 105 °C until a constant weight was obtained. The gravimetric method suggested by (Michael, 1984) [21] was used to determine the percent of moisture content in the soil.

2.3 Soil chemical properties

(Piper, 1966) method was used to test the electrical conductivity of soil water extract. The standard 0.01M potassium chloride solution was used to calibrate the electric conductivity meter before use. The results were expressed as dSm-1. A digital pH meter was used to measure the pH of the soil in a 1:2 suspension of soil and water as per the procedure given by (Jackson, 1973) [13]. Organic carbon was measured by the rapid titration method (1934) described by (Walkley and Black, 1934) [30]. A solution of concentrated sulfuric acid and potassium dichromate was used to digest the soil. The remaining potassium dichromate was determined by titrating a standard ferrous ammonium sulphate solution in the presence of ortho-phosphoric acid using diphenylamine as an indicator,

3. Results and Discussion

3.1 Soil physical attributes

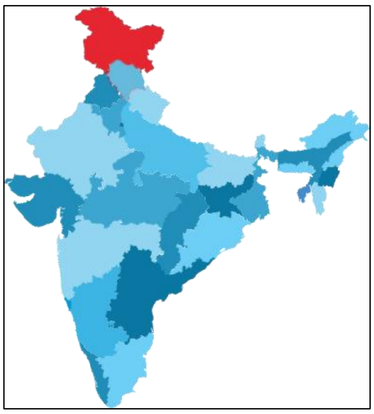
The results revealed that altitude has a considerable impact on the soil physical attributes. Sand showed a significant negative correlation with altitude (r = 0.455, $P<0.01$) and silt (r = 0.713, $P<0.05$). In terms of altitudes highest soil bulk density (BD) was observed in A1 (1.41 g cm^{-3}), followed by A3 (1.32 g cm^{-3}), with the least bulk density of (1.27 g cm^{-3}) at A2 recording. Overall bulk density of the forest range was 1.33. Soil bulk density (BD) decreased when altitude changed from A1 (1.41 g cm^{-3}) to A2 (1.27 g cm^{-3}), then increased further to (1.32 g cm^{-3}) in A3. (Table 1). Silt showed a significant positive correlation with organic carbon (r = 0.497, $P<0.05$) and a strong negative and significant correlation with clay (r =-0.767, $P<0.05$. The decomposition of litter in the A2 resulted in increased organic matter content which increased porosity and reduced bulk density, confirming the results of other related studies (Francaviglia *et al*. 2017) [8] (Soleimani *et al*. 2019). Data reveals that the bulk density showed a significant positive correlation with clay (r = 0.42, $P<0.01$). The bulk density of soil also depends on soil texture, and organic matter (Unger, 1991) [29]. Soil moisture exhibited a significant negative correlation with pH (r = 0.575, $P<0.05$). (Table 3). Consequently, the mean values of soil moisture content were significantly higher in the A2 (27.64%) followed by A3 (25.28%) > A1 (21.53%). Overall moisture content for the forest range was (24.82%) the lowest amount of moisture was in the lowest attitude A1 which increased at A2 but later decreased with increasing altitudes. The bulk density showed a reverse trend with moisture which declined with rising altitude as in seen in the study conducted by (Kumar *et al*., 2019, Imtimongla, 2021) [17, 11]. Soil texture also affects moisture retention which can show variation with catchment topography (Luo *et al.*, 2014) [19]. Analysis of the soil texture shows the particle size distribution of the soil under different altitudes. The particle size distribution of the different altitudes was dominated by silt (%) under various altitudes (Table 1) and the percentage proportion of sand and clay varies. Slit shows less variation in different altitudes. The proportion of clay was minimal, while the content of silt was highest in the middle altitude. The effects of climate on soil properties are crucial determinants of soil weathering, the highest mean sand was recorded in A1 (33.15%) followed by A3 (29.15%) and A2 (26.52%) strata. The overall mean sand of the forest range was (29.73%). The sand content starts to decrease as we move up to A2. However, this trend indicates a propensity for a marginal rise in value for the highest altitude (A3), On the other hand, silt and clay contents show a reverse trend where they increase with altitude till A2 and while a noticeable decrease is observed for the highest altitude at A3. The mean silt was highest for A2 (57.59%) followed by A3 (54.26%), and the lowest average value was obtained for A1 (47.56%). Higher silt but the lower sand proportion was observed at mid (A2) altitude indicating the presence of quartz, feldspars, hornblende, and micas in the soil (Ley *et al.*, 2001) [18]. The mean percentage of clay in the soil was maximum for A1 (18.93%) followed by A3 (16.59%) and the lowest average value was obtained for A2 (15.89%). The texture class was loam for A1, silt loam for A2, and A3.

3.2 Soil chemical attributes

Soil chemical attributes showed a variation based on altitude (Table 2). Analyzed soil samples from the different altitudes were slightly acidic. The highest pH of 6.43 was obtained in A1 followed by A3 where the pH of the soil was 6.22, whereas A2 recorded the lowest pH of 5.97 due to high organic carbon present and litter content in A2. Noticeably lower pH in A2 can be ascribed to its larger content of humic acid via higher organic carbon/matter, a higher degree of precipitation, and a temperature gradient. (Najar *et al.*, 2009) [23]. Low pH could be influenced by the decomposition of pine needles. Overall pH was 6.21 for the forest range. As the altitude shifted from A1 to A2, the organic carbon content (OC) increased and then further decreased when the altitude changed from A2 land to A3. Organic carbon showed a negative and significant correlation with pH (r =-0.632) and EC (r =-0.630). Our results are in conformity with (Yadav *et al.*, 2022) who detected lower values in upper and intermediate zone soils and greater values in lower zone soils and ascribed it to variations in the concentration of organic matter and the effects of erosion. Similar results were reported earlier by (Kirmani, 2004) [16] and (Najar, 2002) [24]. Similar studies were conducted by (Jugran and Tewari 2022) [5] in which the hill base reported the most litter decomposition, whereas the ridge top recorded the lowest litter decomposition. Other studies conducted by (Abate and Kibret 2016) [2] revealed that differences in soil physicochemical parameters are connected to slope location and land use in the Ethiopian highlands. Their research revealed that regions in the upslope location were distinguished by high OM and had low soil pH. They also noticed that lower slope positions reported elevated pH levels. According to (Griffiths *et al.*, 2009) [9], topography can affect the physicochemical characteristics of soil, including OM, soil depth and texture. The mean values of organic carbon were highest (1.68%) in A2 followed by A3 (1.41%) and the minimum value (1.22%) was obtained for A1. Organic carbon shows a contrariwise relation with pH and bulk density as humic acid in soil decreases the pH. In comparison to mineral matter, organic matter is substantially lighter, as a result, organic stuff reduces bulk density. The overall mean for the total forest range was (1.43%) organic carbon. Climate is an essential factor influencing humus accumulation (Zanella *et al.*, 2018) [35]. Organic carbon showed a positive significant correlation with soil moisture (r =0.533, P<0.05). The more favourable conditions for organic matter decomposition are high temperature, adequate soil moisture, and a high amount of litter (Salmon 2018). High altitudes have low decomposition rates of organic matter as the temperature tends to decrease with an increase in altitude. Vegetation at high altitudes is also scattered with less biomass accumulation due to low temperatures. Steep slopes also lose organic matter due to soil erosion. (Balba, 2018) [4] indicated that steep slopes are typified by rapid runoff. Soil EC measures the amount of dissolved substance in an aqueous solution that corresponds to the substance's capacity to carry an electric current. The overall mean of electrical conductivity for various altitudes in the present investigation was found to be 0.31 dSm^{-1} as presented in Table. The highest electrical conductivity of 0.35 dSm^{-1} was found in A1 followed by A3 of 0.31 dSm^{-1} and the lowest value of 0.27 dSm^{-1} of electrical conductivity was found in A2. There were no significant differences in EC. These results suggest that EC does not change much with altitude. Lower altitude sites have more cumulative salt deposition than higher altitude sites, This could be caused by the increased buildup of base-forming cations such as Ca^{+2}, Mg^{+2}, K^{+}, and $CaCO_3$ (Northcott *et al.*, 2009) [25].

3.3 Statistical analysis

The correlation coefficient was worked out between soil physicochemical properties and altitude as shown in Table 3. Data reveals that the bulk density showed a significant positive correlation with clay (r = 0.42, P<0.01). Sand showed significant negative correlation with altitude (r = 0.455, P<0.01) and silt (r = 0.713, P<0.05). Silt showed a significant positive correlation with organic carbon (r = 0.497, P<0.05) and a strong negative and significant correlation with clay (r =-0.767, P<0.05). Organic carbon showed a negative and significant correlation with pH (r =-0.632) and EC (r =-0.630) However, organic carbon showed a positive significant correlation with both soil moisture (r =0.533, P<0.05). Soil moisture exhibited a significant negative correlation with pH (r = 0.575, P<0.05).



a. Jammu and Kashmir

b. Ganderbal district

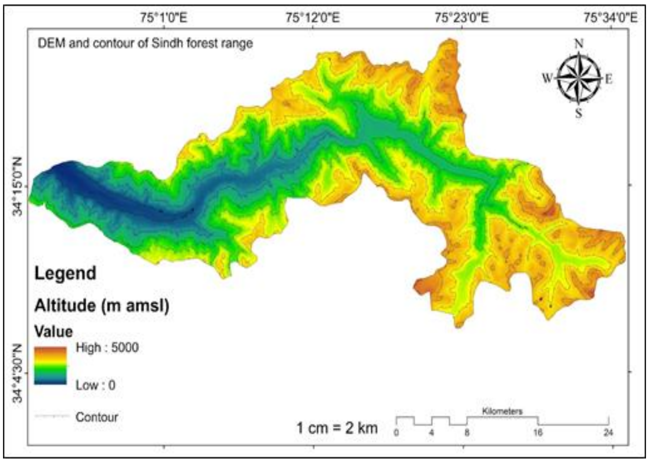


Fig 1: Study area DEM and contour (Sindh forest range, Ganderbal, Jammu and Kashmir)

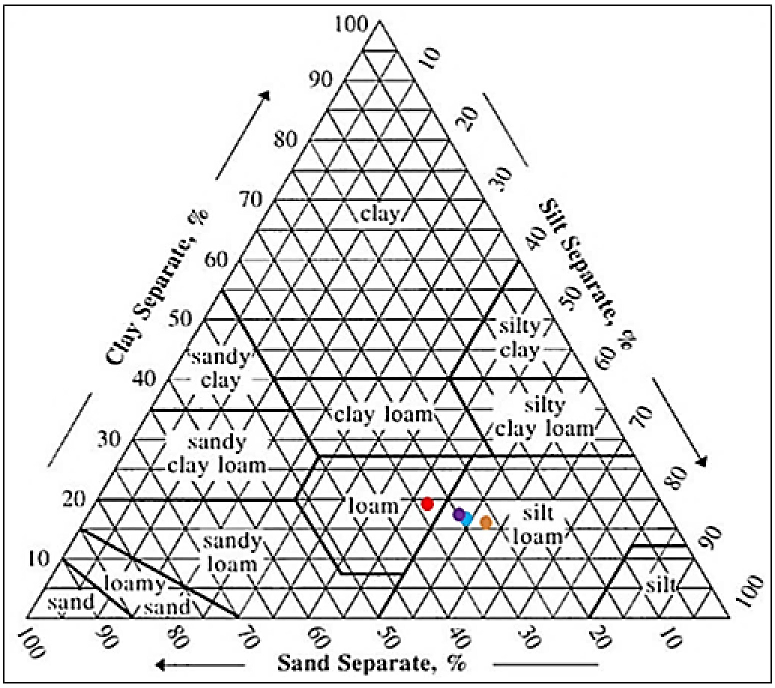


Fig 2: Soil texture triangle, showing the major textural classes at different altitudes in Sindh Forest Range defined by the USDA

Table 1: Altitudinal variations in soil physical properties of the Sindh forest range

Sites	Altitudes	Bulk density (g/cm^{-3})	Moisture (%)	Sand (%)	Silt (%)	Clay (%)	Texture class (USDA)
		Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	
A1 (Lower)	1800-2200	1.41±0.09	21.53±0.75	33.15±1.48	47.56±2.08	18.93±1.85	Loam
A2 (Middle)	2200-2600	1.27±0.05	27.64±1.55	26.52±0.72	57.59±0.77	15.89±0.97	Silt Loam
A3 (Upper)	>3000	1.32±0.03	25.28±2.22	29.15±0.44	54.26±1.74	16.59±1.47	Silt Loam
	Overall mean	1.33 ±0.03	24.82±1.03	29.73±0.79	53.14±1.22	17.14±0.86	Silt Loam

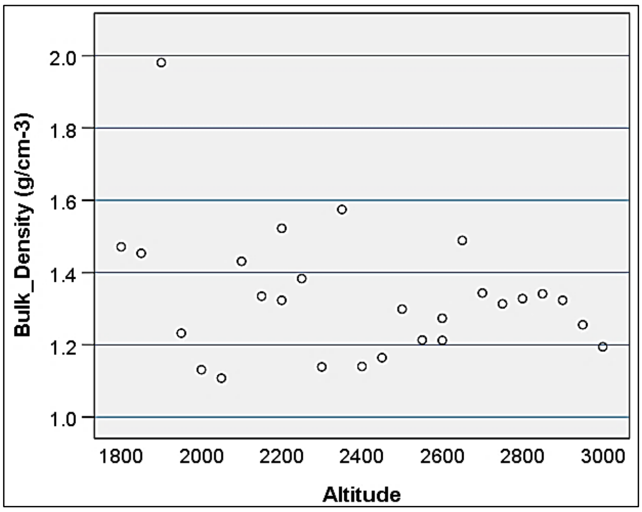
Table 2: Altitudinal variations in soil chemical properties of Sindh forest range

Sites	Altitudes	Organic carbon (%)	pH	Electrical conductivity (dSm^{-1})
		Mean ± SE	Mean ± SE	Mean ± SE
A1 (Lower)	1800-2200	1.22±0.06	6.43±0.11	0.35±0.01
A2 (Middle)	2200-2600	1.68±0.10	5.97±0.19	0.27±0.02
A3 (Upper)	>3000	1.41±0.04	6.22±0.14	0.31±0.02
	Overall mean	1.43±0.05	6.21±0.09	0.31 ±0.01

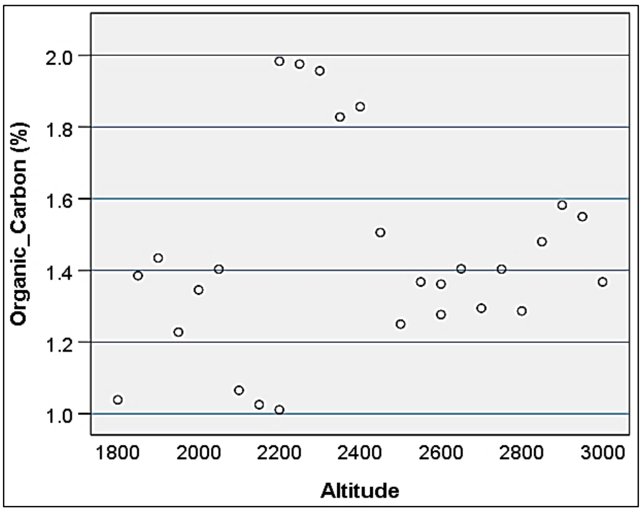
Table 3: Correlation between altitude and physicochemical properties of soil

	Altitude	BD (g/cm^{-3})	Sand (%)	Silt (%)	Clay (%)	OC (%)	Moisture (%)	pH	EC
Altitude	1								
BD (g/cm^{-3})	-0.294	1							
Sand (%)	-0.455*	0.042	1						
Silt (%)	0.476*	-0.324	-0.713**	1					
Clay (%)	-0.26	0.421*	0.098	-0.767**	1				
OC (%)	0.14	-0.138	-0.408*	0.497**	-0.333	1			
Moisture (%)	0.211	-0.177	-0.141	0.264	-0.246	0.533**	1		
pH	-0.12	0.137	0.195	-0.283	0.224	-0.632**	-0.575**	1	
EC (dSm^{-1})	-0.163	0.188	0.361	-0.374	0.202	-0.630**	-0.376	0.236	1

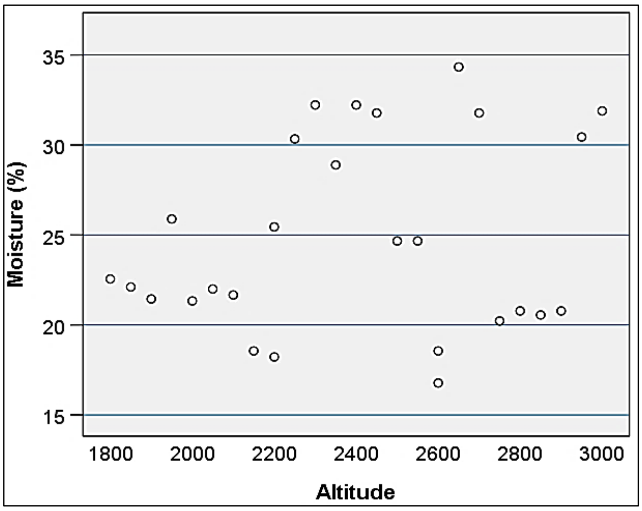
**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).
BD = Bulk_Density (g/cm^{-3}); OC= Organic carbon (%); EC = Electrical conductivity(dSm^{-1}).



(a)



(b)



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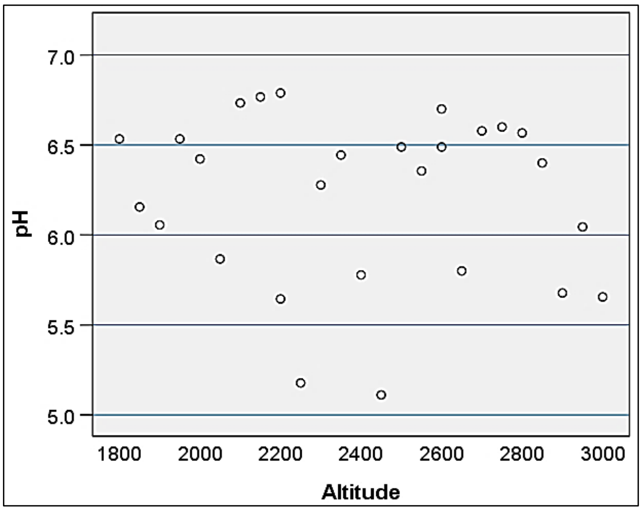

(d)

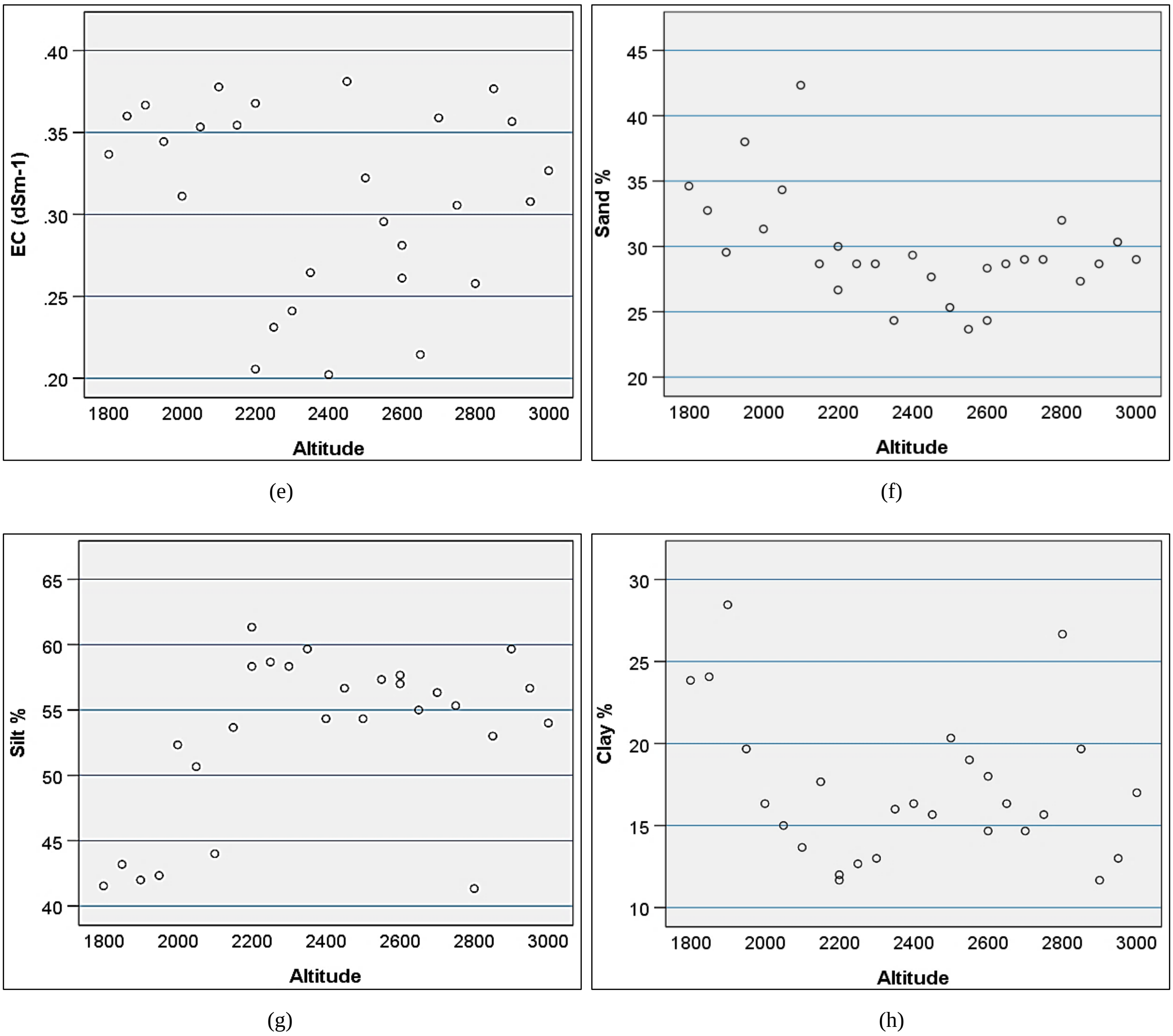

Fig 3: Scatterplots for soil sample parameters with altitude in the study area; a. Bulk Density (g/cm^{-3}) (BD); b. Organic Carbon (%); c. Moisture (%); d. pH; e. EC (dSm^{-1}); f. Sand (%); g. Silt (%) and h. Clay (%)

Conclusions

The present investigation revealed that physicochemical properties changed at different altitudes. The texture class was loam for A1, silt loam for A2, and A3. The particle size distribution at the different altitudes was dominated by Silt (%). The sand content starts to decrease as we move up to A2. However, this trend shows a slight increase in value for the highest altitude (A3), this may be a result of erosion from a higher elevation removing the finer fractions, followed by deposition in lower gently sloping places. Soils on the steeper slope showed a greater amount of weathering than on the gentle slope, higher silt but the lower sand proportion was observed at mid-altitude indicating the presence of quartz, feldspars, hornblende, and micas in the soil. Soil pH is acidic to neutral as Soil is fertile with high organic content. Analyzed soil samples from the different altitudes were slightly acidic (pH <7). Lower pH in mid-altitude may be attributed to a higher amount of organic carbon and decomposition of forest litter. The process of humus formation is significantly influenced by the altitudinal gradient. Organic carbon content (OC) increased with altitude but decreased at alpine zones which can be due to temperature as low-temperature conditions are not favourable for organic matter decomposition and high amount of forest litter. The differentiation of soil properties depends significantly on organic carbon as organic carbon is crucial in the soil development process. Lower altitude sites have greater cumulative salt accumulation than higher altitude sites, according to differences in EC, but there is no significant relationship between the EC and altitude. The results can be used to understand the interactive relationships between altitudes and soil properties in forests of western Himalayan region to implement protection plans, increase plant biodiversity, and restore these forests. Understanding the spatial distribution of soil characteristics as influenced by topographical features is critical for assessing the effect of climate change on the soil.

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Conflict of interest

I, Mir Rizwan Qazi, as a Corresponding Author, confirm that none of the other authors have any conflicts of interest related to this publication.

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