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Effects of Anthropogenic Disturbance on Soil Characteristics in a Forest of Aizawl District, Mizoram

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Abstract

Objectives: Terrestrial ecosystems depend on forests for various services and functions, which are vital to biodiversity. The study examines anthropogenic impacts on soil quality caused due to anthropogenic disturbance. **Methods:** Three research sites (undisturbed, moderately disturbed, and highly disturbed forest stands) were selected, based on the degree of disturbance considering the canopy cover. Soil samples were collected from two depths i.e., 0-10 cm (topsoil) and 10-20 cm (subsoil) depths on the seasonal basis (pre-monsoon, monsoon, and post-monsoon seasons) and analysed for various characteristics namely, bulk density, pH, organic carbon content, moisture content, and nutrient availability (potassium, phosphorus, and nitrogen). **Findings:** With a range of 17.44 $\pm$ 0.52% to 44.13 $\pm$ 0.48%, the results showed an inverse relationship between the degree of disturbance and soil moisture. Soil bulk density values ranging from 0.71 $\pm$ 0.11 g/cm^3 to 1.36 $\pm$ 0.01 g/cm^3 and soil compaction increased with disturbance. The less disturbed site had a greater acidic level, with pH range of 4.59 $\pm$ 0.06 to 5.88 $\pm$ 0.03. Higher concentrations in topsoil showed a substantial variation in the organic carbon content (0.92 $\pm$ 0.03%-3.66 $\pm$ 0.19%). In contrast to disturbed stands, undisturbed stands have significantly better nutrient availability. The results demonstrate how anthropogenic disturbance impairs soil health. **Novelty:** Unlike many studies which focus on general forest degradation, the present study shows how anthropogenic activities like jhum cultivation and unsustainable logging have affected the soil health of Mizoram's forests along various degree of disturbance. It also highlights how seasonal variation affects soil health. The study shows the importance of implementing sustainable forest management practices to prevent soil degradation.

Keywords: Anthropogenic disturbance; Forest; Soil nutrient; Seasonal variation; Soil depth

1 Introduction

Forests offer a variety of services and functions that are essential for biodiversity. Soil, a basic component of terrestrial ecosystem, is comprised of organic matter, water, roots, animals, and microbes [1]. Anthropogenic disturbances have been one of the primary causes of soil and forest ecosystem deterioration recently [2]. Increased soil erosion, nitrogen loss, and a decline in soil microbes that maintain soil structure and quality are all results of excessive human interference [3]. Reduced plant biomass, especially fine root and leaf litter, from increased disturbance changes the microclimate and substrate availability and lowers the amount of nutrients returned to the soil [4]. Particularly in hilly regions, the frequent removal of vegetation through human activities results in soil degradation through erosion processes or lead to water logging, causing volatilisation and nutrient leaching, depleting the soil of certain nutrients. Thus, regular soil quality monitoring is essential to the preservation of forests [5]. Soil physico-chemical properties play a significant role in determining soil productivity and forest quality, both of which are critical for maintaining ecological and forest services, due to the close relationship between vegetation and soil in forests and the potential for vegetation changes to produce distinct soil structures [6]. Situated within the Indo-Burma hotspot, Mizoram boasts the highest percentage of forest cover among all Indian states. The Forest Survey of India (FSI) estimates that the state's entire area is 84.53% or 17,820 km^2 of forest covered [7]. In the Northeastern part of India, there are numerous studies have been carried out to comprehend the physio-chemical and biological characteristics of the soil in various forest types [2], [4], [6], but there is little information on differences in soil properties, particularly with regard to disturbance gradient [8]. The forest in Hmuifang, a popular tourist destination, has been impacted, particularly for jhum cultivation, as locals are heavily dependent on the forest for livelihood. The potential for tourism to increase demand for firewood, building materials, etc. may also result in the exploitation of the forest. Keeping this in mind, the current study was carried out in the Hmuifang forest in Aizawl district of Mizoram, with an aim to examine the impacts of anthropogenic disturbance on soil at varying levels of human disturbance. We hypothesize that anthropogenic disturbance has detrimental effect on soil health. Also, soil organic carbon and soil nutrients decline with increasing level of disturbance.

2 Methodology

2.1 Description of study site

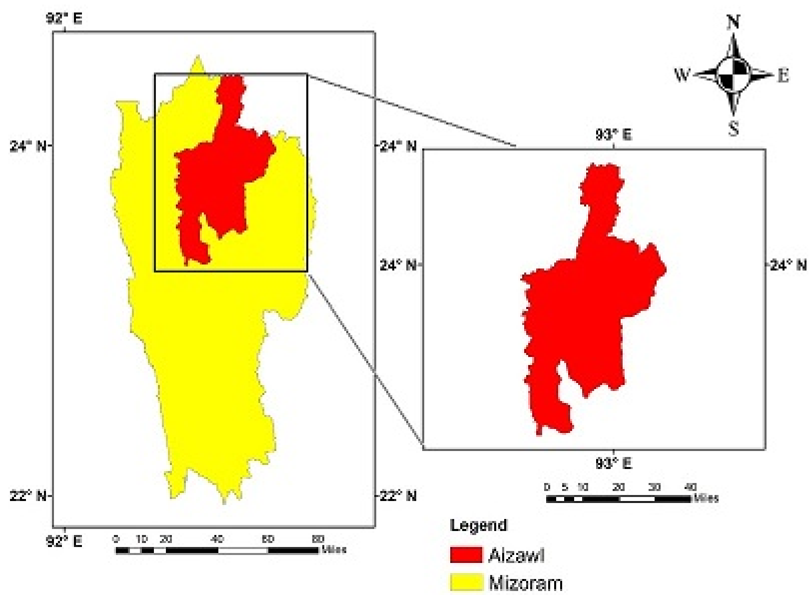

Fig 1. Map of Aizawl district, Mizoram

The study was conducted at Hmuifang, a popular tourist destination in Mizoram's Aizawl district, which is located between coordinates 23°27'00" N and 23°27'24" N latitude and 92°45'03" E and 92°45'33" E longitude. The average elevation of the forest area is 1619 meters above sea level. The study area is classified as having a humid subtropical climate by the Koppen Climate

Classification. Temperatures range from 20° to 29° Celsius in the summer and 7° to 21° Celsius in the winter, with an average of 267.13 mm of rainfall each year.

2.2 Data collection

Based on the disturbance gradient, the study area was further divided into three distinct forest stands. To quantify the degree of disturbance, canopy cover and disturbance index were determined based on the number of cut or severed trees, expressed as the percentage taken into consideration following the work done by other researchers[1]. Based on the level of disturbance, the study site was divided as: undisturbed (UD) stand (>50% canopy cover and <10% DI), moderately disturbed (MD) stand (20-50% canopy cover and 10-50% DI), and highly disturbed (HD) stand (<20% canopy cover and >50% DI).

2.2.1. Methods

The study was conducted during 2023 and a total of 54 samples (3 composite x 2 depth x 3 site replicates x 3 forest stands) were collected from the study area by inserting a 10cm scaled soil corer with 5.2cm inner diameter. The soil samples were collected from two depths: 0–10 cm (topsoil) and 10–20 cm (subsoil). Standard laboratory methods used by various researchers[2],[9] were applied to examine the properties of the soil samples. Using a pH meter, the soil's pH was measured in a 1:5 soil: water solution. After the fresh weights were attained, the samples were left to dry in hot air oven at 105°C until constant weight was attained to determine the Soil moisture content (SMC) and Bulk density (BD) using gravimetric method and core method respectively. Soil organic carbon (SOC) and available nitrogen ($N_{avail.}$) were calculated using Walkey-Black titrimetric method and Kjeldahl distillation and titration method respectively, while available potassium (K_{avail}). and available phosphorus (P_{avail}). were determined following flame photometer method and spectrophotometer method respectively.

2.2.2. Statistical analysis

Statistical parameters like mean and standard error of the mean, were calculated in MS Excel. ANOVA and Pearson correlation were also applied using SPSS 27 to know the correlation between disturbance and various soil parameters.

3 Results and Discussion

The different properties of soil and correlation analysis were carried out and data were presented and discussed.

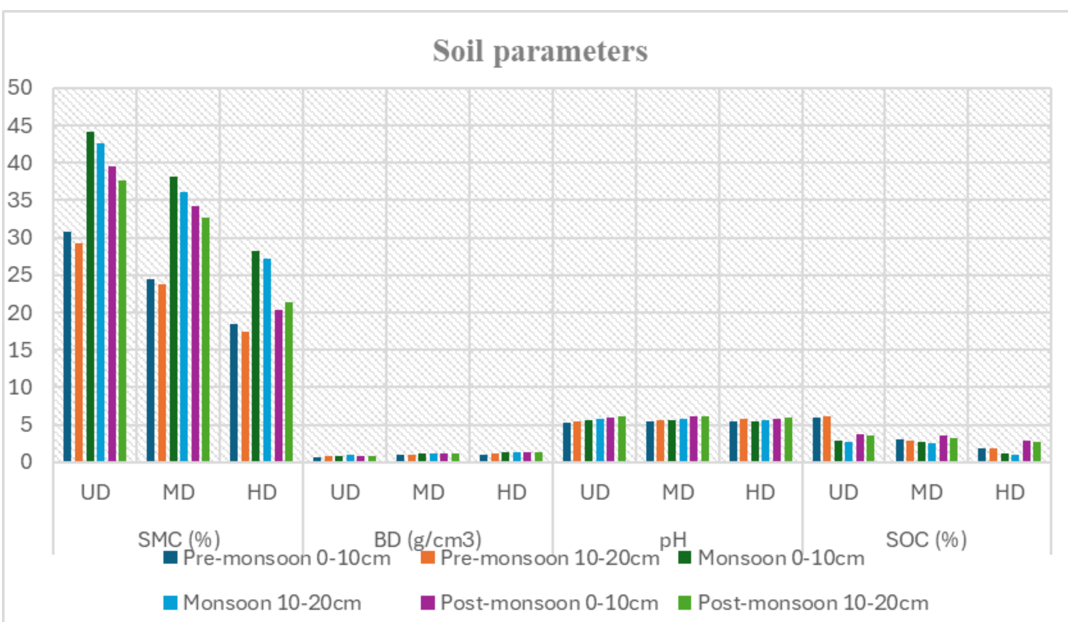

Fig 2. Changes in soil parameters along different levels of disturbance

The SMC ranged from 17.44 ± 0.52% (pre-monsoon season, HD stand) to 44.13 ± 0.48% (monsoon season, UD stand) (Table 1, Figure 2), with the monsoon season having the highest SMC and the pre-monsoon season having the lowest, aligning

Table 1. Soil properties of selected forest stand in Aizawl district, Mizoram

Forest stand	Seasons	Soil depth (cm)	Soil moisture content (%)	Bulk density (g/cm^3)	pH	Organic Carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
UD	Pre-monsoon	0-10	30.78 ± 0.53	0.71 ± 0.11	5.27 ± 0.04	3.19 ± 0.33	172.09 ± 0.90	28.34 ± 0.36	191.62 ± 2.07
		10-20	29.18 ± 0.84	0.78 ± 0.11	5.43 ± 0.05	3.06 ± 0.34	146.30 ± 2.51	27.34 ± 0.46	167.13 ± 1.30
MD		0-10	24.51 ± 0.48	0.92 ± 0.02	5.48 ± 0.19	2.98 ± 0.13	122.79 ± 2.08	19.10 ± 0.16	147.63 ± 1.62
		10-20	23.71 ± 0.96	0.96 ± 0.02	5.65 ± 0.17	2.90 ± 0.14	100.41 ± 2.02	17.91 ± 0.21	130.09 ± 1.07
HD		0-10	18.41 ± 0.56	1.02 ± 0.02	5.51 ± 0.02	1.91 ± 0.10	100.09 ± 2.93	14.32 ± 0.49	59.58 ± 1.76
		10-20	17.44 ± 0.52	1.09 ± 0.02	5.71 ± 0.05	1.77 ± 0.10	87.62 ± 2.28	10.58 ± 0.22	43.43 ± 1.05
UD	Monsoon	0-10	44.13 ± 0.48	0.86 ± 0.07	5.62 ± 0.05	2.84 ± 0.17	152.27 ± 2.33	24.02 ± 0.15	170.28 ± 1.67
		10-20	42.62 ± 0.51	0.93 ± 0.06	5.84 ± 0.06	2.71 ± 0.19	126.86 ± 1.68	22.65 ± 0.51	155.72 ± 1.85
MD		0-10	38.22 ± 0.41	1.17 ± 0.01	5.65 ± 0.04	2.64 ± 0.29	117.23 ± 1.68	17.94 ± 0.17	73.91 ± 2.79
		10-20	36.04 ± 0.6	1.23 ± 0.02	5.85 ± 0.05	2.54 ± 0.29	100.66 ± 0.55	16.82 ± 0.38	59.05 ± 2.75
HD		0-10	28.16 ± 0.53	1.35 ± 0.01	5.41 ± 0.07	1.21 ± 0.00	94.48 ± 2.66	9.68 ± 0.45	51.26 ± 2.65
		10-20	27.23 ± 0.30	1.38 ± 0.01	5.58 ± 0.09	0.92 ± 0.03	82.61 ± 2.77	6.84 ± 0.67	39.33 ± 1.75
UD	Post-monsoon	0-10	39.56 ± 0.34	0.77 ± 0.05	5.97 ± 0.03	3.66 ± 0.19	200.15 ± 3.43	31.90 ± 1.21	207.41 ± 0.80
		10-20	37.67 ± 0.55	0.83 ± 0.04	6.13 ± 0.03	3.53 ± 0.18	182.01 ± 1.16	30.15 ± 0.84	183.96 ± 1.85
MD		0-10	34.18 ± 0.11	1.13 ± 0.02	6.06 ± 0.04	3.50 ± 0.21	134.15 ± 1.23	20.19 ± 0.28	168.33 ± 1.13
		10-20	32.66 ± 0.53	1.17 ± 0.05	6.20 ± 0.05	3.16 ± 0.22	122.72 ± 0.88	19.21 ± 0.24	151.87 ± 1.69
HD		0-10	20.30 ± 0.48	1.29 ± 0.18	5.76 ± 0.06	2.78 ± 0.32	108.41 ± 3.10	18.00 ± 0.25	81.84 ± 0.85
		10-20	21.40 ± 0.54	1.34 ± 0.18	5.91 ± 0.07	2.66 ± 0.31	96.33 ± 1.61	17.24 ± 0.21	74.51 ± 1.18

UD- undisturbed, MD- moderately disturbed, HD- highly disturbed

with previous work of other researchers (2), (10). The topsoil retained more moisture than the subsoil. In contrast to HD stands, which displayed decreased moisture due to plant loss and soil degradation, UD stands had higher SMC because of their dense canopy cover and superior root systems (11).

BD in the study area ranged from 0.71 ± 0.11 g/cm^3 (pre-monsoon season, UD stand) to 1.38 ± 0.01 g/cm^3 (monsoon season, HD stand) (Table 1, Figure 2), highest during the monsoon due to soil moisture and compaction. The values were in line with those of other researchers (8), (12). The bulk density of soil increased with increase in soil depth and disturbance level (UD<MD<HD), due to higher compaction in deeper layers and decreased organic matter (2).

The pH, one of the most crucial factors in determining the health of soil, was found to be acidic, ranging from 5.27 ± 0.04 (pre-monsoon season, UD stand) to 6.13 ± 0.03 (post-monsoon, UD stand) (Table 1, Figure 2), comparable to other researchers (2), (10), (13). Higher pH in the HD stand during pre-monsoon season is well attributed to the release of cations as

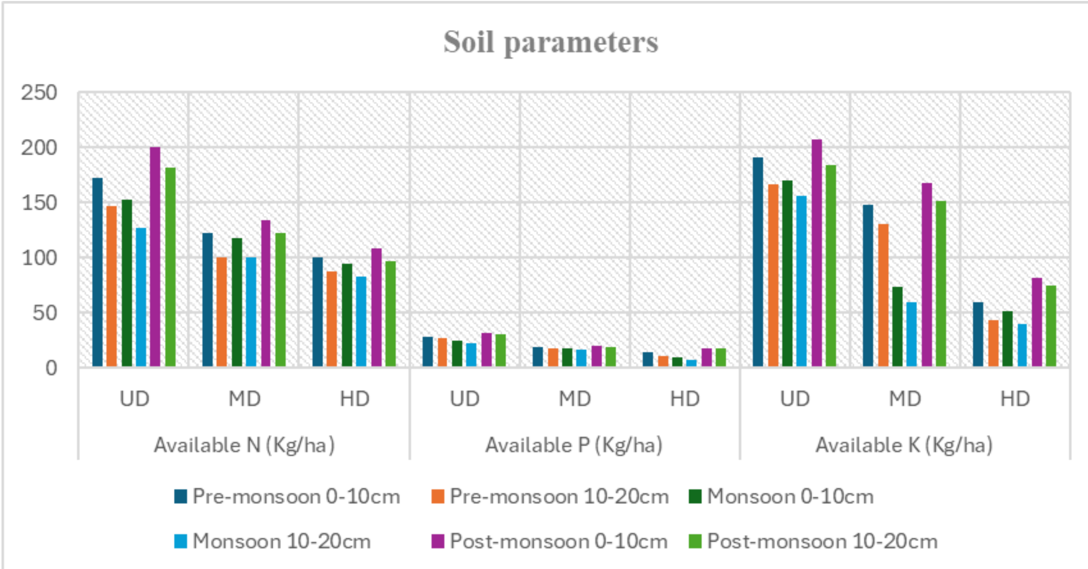

Fig 3. Changes in soil macronutrients along different levels of disturbance

a result of jhum cultivation. Burning enhances the release of nutrients in the soil and thus increases the pH of the soil[13]. During the dry season, the soil's acidity was higher than it was during the wet season. The leaching of calcium carbonate and exchangeable bases, particularly in the presence of heavy rainfall, may be the cause of the acidity of the soil[10].

Following the pattern UD > MD > HD, SOC ranged from 0.92 $\pm$ 0.03% (monsoon season, HD stand) to 3.66 $\pm$ 0.19 % (post-monsoon season, UD stand) (Table 1, Figure 2), like other researchers[10],[12]. Favourable soil conditions and increased microbial activity because of moisture may lead to higher SOC in UD stands. The reduction of vegetation and nutrient loss through runoff may be the cause of lower SOC in HD stands during monsoon. According to earlier research[6],[10],[12], SOC was greater in topsoil (0-10cm), due to decomposition and litter input.

$N_{avail.}$ decreased with increasing disturbance and soil depth, which was consistent with findings of another researcher[2], ranging from 200.15 $\pm$ 3.43 kg/ha (post-monsoon, UD stand) to 82.61 $\pm$ 2.77 kg/ha (monsoon, HD stand) (Table 1, Figure 3). More N-fixing bacteria, leguminous plants, and litter decomposition may contribute to higher nitrogen levels in topsoil, particularly in UD stand[12], where seasonal variation revealed increased $N_{avail.}$ during post-monsoon, but monsoon leaching probably decreased nitrogen in disturbed stands.

$P_{avail.}$ levels were consistently higher in UD stands throughout all seasons, ranging from 6.84 $\pm$ 0.67 kg/ha (HD stand, monsoon) to 31.90 $\pm$ 1.21 kg/ha (UD stand, post-monsoon) (Table 1, Figure 3). Similar values were recorded by other researchers[10],[12]-[13]. Also, $P_{avail.}$ dropped as soil depth and disturbance increased[10]. Regardless of the season, the UD stand had a higher $P_{avail.}$ content, and the values in the soil at higher depths were higher than those at lower depths. Researchers also noted a similar declining trend in the amount of $P_{avail.}$ from the UD to the HD stand[2],[10]. While UD stand has higher $P_{avail.}$, likely due to more organic matter releasing compounds enhancing phosphorus availability, highly disturbed stand has least $P_{avail.}$ with less vegetation and litter fall, decreasing nutrient cycling.

The $K_{avail.}$ ranged between 39.33 $\pm$ 1.75kg/ha (HD stand, monsoon) and 207.41 $\pm$ 0.80kg/ha UD stand, post-monsoon) (Table 1, Figure 3). The values are similar with another research[2],[14] and indicates that $K_{avail.}$ is decreased with greater disturbance. Leaching may result in nutrient transfer to the bottom soil layer. But through nutrient cycle the nutrients return to the topsoil through the breakdown and decomposition of litter fall and other organic materials, which results in a high concentration of K[6].

A correlation analysis between disturbance, soil depth, and other soil metrics is shown in Table 2. A researcher[15] stated that there is little to no correlation when values are less than 0.2, while values between 0.9 and 1.00 can be classified as very highly correlated, values between 0.7 and 0.9 as highly correlated, values between 0.5 and 0.70 as moderately correlated, those between 0.25 and 0.50 as low. Disturbance and BD had a positive connection ($r = 0.741$, $p<0.01$), indicating that disturbance may compact soil. Additionally, SMC, SOC, and key nutrients like K_{avail}, P_{avail}, and N_{avail} are all negatively impacted by disturbance, indicating that it significantly reduces soil fertility. Interestingly, there's a negative correlation between BD and SMC ($r=-0.322$, $p<0.05$), meaning that compacted soil holds less moisture[2],[12],[6]. There is a positive association ($p<0.01$) between

Table 2. Pearson correlation analysis between disturbance, depth and soil parameters

	Disturbance	Depth of soil	SMC (%)	BD (g/cm3)	pH	SOC (%)	Avail. K (kg/ha)	Avail. P (kg/ha)	Avail. N (kg/ha)
Disturbance	1	0.000	-.762**	.741**	-0.09	-.656**	-.876**	-.880**	-.844**
Depth of soil		1	-0.070	0.120	.313*	-0.101	-0.144	-0.121	-0.262
SMC (%)			1	-.322*	0.300*	.391**	.558**	.555**	.601**
BD (g/cm^3)				1	0.081	-.494**	-.716**	-.712**	-.701**
pH					1	0.320*	0.198	0.191	0.168
SOC (%)						1	.783**	.809**	.692**
Avail. K (kg/ha)							1	.899**	.886**
Avail. P (kg/ha)								1	.928**
Avail. N (kg/ha)									1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 3. Test of between-subjects for Anova

		Sum of Squares	df	Mean Square	F	Sig.
Season	Between Groups	0.00	2.00	0.00	0.00	1.00
	Within Groups	36.00	51.00	0.71		
Depth (cm)	Between Groups	0.00	2.00	0.00	0.00	1.00
	Within Groups	13.50	51.00	0.26		
SMC (%)	Between Groups	2109.31	2.00	1054.65	36.96	0.00
	Within Groups	1455.24	51.00	28.53		
BD (g/cm^3)	Between Groups	1.74	2.00	0.87	33.39	0.00
	Within Groups	1.33	51.00	0.03		
pH	Between Groups	0.26	2.00	0.13	1.70	0.19
	Within Groups	3.91	51.00	0.08		
SOC (%)	Between Groups	17.26	2.00	8.63	25.01	0.00
	Within Groups	17.60	51.00	0.35		
Available N (kg/ha)	Between Groups	44013.40	2.00	22006.70	74.75	0.00
	Within Groups	15015.48	51.00	294.42		
Available P (kg/ha)	Between Groups	1953.90	2.00	976.95	93.57	0.00
	Within Groups	532.46	51.00	10.44		
Available K (kg/ha)	Between Groups	131935.60	2.00	65967.80	84.03	0.00
	Within Groups	40035.37	51.00	785.01		

SMC and SOC, K_{avail}, P_{avail}, and N_{avail}, indicating that better nutrient retention is facilitated by more moisture[3]. The BD of soil is significantly inversely correlated with K_{avail}, P_{avail}, N_{avail}, and SOC, suggesting that denser soil generally contains lower levels of nutrients and organic carbon. The BD of soil is significantly inversely correlated with K_{avail}, P_{avail}, N_{avail}, and SOC, suggesting that denser soil generally contains lower levels of nutrients and organic carbon[12],[6]. Given its crucial role in soil fertility, there is a strong positive link between SOC and K_{avail}, P_{avail}, and N_{avail}[3]. K_{avail}, P_{avail}, and N_{avail} also have a high correlation ($p<0.01$), indicating that they increase or fall together. So, it can be concluded that minimizing disturbance is crucial for maintaining healthy, nutrient-rich soils. ANOVA was used to find out how disturbance affected different soil parameters (Table 3). There was no significant effect of disturbance on season, depth and pH, while there was highly significant difference in SMC, BD, SOC and soil macronutrients between forest stands.

Jhum cultivation is one of the primary causes of forest degradation in the study area, leading to deforestation, soil erosion, and biodiversity loss, as the jhum cycle period is shorter, which results in insufficient time for the forest and soil to recover[14]. In addition, the extraction of firewood for fuel, food, medicine, animal grazing, etc., also contributes to forest degradation.

The current study examines the effects of anthropogenic disturbance on soil; however, because of the short duration of the study and lack of microbial parameter estimation, it may not be able to capture long-term ecological responses.

4 Conclusion

This study highlights the significant impacts of human disturbance on the soil qualities of the Hmuifang forest, Aizawl district in Mizoram. From undisturbed to severely disturbed forest stands, key soil parameters such as organic carbon, moisture content, and the availability of macronutrients (potassium, phosphorus, and nitrogen) showed a declining trend, while bulk density and pH increased with disturbance. These changes have a negative effect on soil fertility of the forest. Therefore, proper forest and soil management techniques like agroforestry, expansion of jhum cycle period, sustainable extraction of forest products, and organizing forest conservation awareness campaigns for locals must be implemented for maintaining soil fertility.

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