



Enhancing Soil Quality Monitoring for Sustainable Forest Management in Northeast India: Role of Soil Quality Index in Hongmong Conservation Area, Nagaland

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Abstract: Forest degradation in Northeast India has raised concerns regarding soil health, particularly in regions like Nagaland, where forests are vital for indigenous communities' sustenance. This study aimed to assess soil quality and create a Soil Quality Index (SQI) in Hongmong conservation area, Mon District, Nagaland. Soil samples were collected monthly from November 2020 to October 2021 at different altitudinal zones and analyzed for various parameters. Principal Component Analysis (PCA) was used to identify a Minimum Data Set (MDS), and SQI was derived using Additive and Weighted methods. There were significant seasonal variation in soil properties across different depths and sites. Soil pH, moisture content, organic carbon, and nutrient levels were significantly influenced by altitude and seasonal changes. Soil bulk density increased with decreasing organic carbon, while clay and silt content increased with altitude. PCA identified key soil factors contributing to soil quality across sites. The creation of SQI revealed variations in soil quality, with both methods providing accurate assessments. The study underscores the importance of SQI in monitoring soil health, aiding sustainable land management practices. Findings highlight the efficacy of SQI in evaluating soil conditions and guiding conservation efforts in Nagaland's forest ecosystems.

Keywords: Soil quality assessment, Forest degradation, Northeast India, Soil quality index

Forest degradation in the Northeast region of India, attributed to factors such as logging, human settlement, and suboptimal land use practices, has led to a notable decline in forest cover over time (Semy et al., 2021, Temjen et al., 2022). This decline raises significant concerns, particularly considering the pivotal role forests play in sustaining the livelihoods of indigenous communities in the region (Banerjee and Madhurima 2013). Nagaland, situated in Northeast India, boasts a reported forest cover of 75.31%, upon which tribal populations heavily depend for sustenance, encompassing food, medicinal resources, and essential commodities, despite their primary involvement in Jhum cultivation (Jamir et al., 2008). The practice of Jhumming, in particular has contributed to the deterioration of forest cover in the region (Temjen et al., 2021).

Within forest ecosystems, soil is crucial in facilitating biomass production and carbon sequestration (Moffat 2003). Organic matter from forest litterfall significantly enriches soil carbon and nitrogen content (Temjen et al., 2021). However, forest soil quality remains vulnerable to adverse impacts from natural phenomena and human activities, consequently compromising its overall health (Verma and Jayakumar 2012). Therefore, an urgent need exists to establish precise soil quality indicators capable of discerning the effects of various disturbances on soil properties (Moffat 2003).

One practical approach for assessing soil quality involves the development of a Minimum Data Set (MDS) for soil

monitoring. This reduces both the cost and labor intensity associated with monitoring sites. This can be achieved by applying dimension reduction techniques such as Principal Component Analysis (PCA) (Semy et al., 2021, Temjen et al., 2022). Creating an MDS also facilitates the derivation of a Soil Quality Index (SQI), which integrates diverse soil attributes into a numerical value, aiding local stakeholders and researchers in promptly evaluating soil conditions (Mukhopadhyay et al., 2016). The SQI value ranges from zero to one, with higher values denoting superior soil quality (Mukherjee and Lal 2014). Consequently, SQI serves as a valuable tool for advancing sustainable management objectives and facilitating site productivity monitoring (Andrews et al., 2002).

Despite previous applications of SQI to assess soil quality in contexts such as Jhum lands and coal mining areas (Semy et al., 2021, Temjen et al., 2022), a notable research gap exists concerning the feasibility of employing this technique in mountainous regions, particularly those within the Mon district. Therefore, with a focus on the beneficial aspects of SQI, the present study endeavors to address this gap and contribute to the body of knowledge in this field.

MATERIAL AND METHODS

Study site: The study site, Hongmong conservation area covering 3200 hectares is located at Angphang Village under Mon district, Nagaland. It is 71 km away from Mon

Headquarters. The study area is located in Mon district of Nagaland, bordered by the Tuensang district in the south, Longleng in the west, Sibsagar district of Assam in the northwest, Myanmar in the east and Longding district of Arunachal Pradesh in the northeast. This study was executed by marking three plots at different altitudinal zones. The lower zone (Site I) is at 1478 m.a.s.l N 26° 30.057'E 095° 00.317', the middle zone (Site II) at 1790m.a.s.l N 26° 29.919'E 095° 00.660' and the upper zone Site III at 2118 m.a.s.l N 26° 29.781'E 095° 00.886'.

Soil sample collections: From November 2020 to October 2021, the first week of each month, soil samples were taken from the three Sites. Eventually, four seasonal mean values were identified from the monthly data: Winter (November, December, and January), spring (February, March, and April), summer (May, June, and July), and autumn (August, September, and October). Samples of soil were taken at three different depths: 0–10 cm, 10–20 cm, and 20–30 cm. Air-dried soil samples were used to examine all the parameters except bulk density and soil moisture. A digital pH meter (1:5 w/v) was used to measure the pH. Table 1 depicts the various soil parameters studied.

Selection of minimum data set: To identify the minimum data set (MDS), conducted principal component analysis (PCA) using SPSS version 26.0. Factors resulting from varimax rotation with eigenvalues greater than 1, explaining a minimum of 5% of the data set's variation, were selected as the MDS for each site (Mandal et al., 2008). Pearson's correlation test was employed to mitigate redundancy among highly weighted variables (Yu et al., 2018). Subsequently, the MDS with the highest scores were retained from each Principal Component as per Semy et al. (2021) and Temjen et al. (2022).

Creation of SQI: First, the score of each soil indicator retained in the MDS was scored as per methods utilized by Semy et al., (2021) and Temjen et al. (2022) with values ranging from zero to one via a linear scoring method. Next, the Additive quality index (Nabiollahi et al., 2017) and the weighted quality index (Raiesi 2017) were estimated to know which method provided accurate results.

Statistical analyses: All statistical analysis were performed using SPSS version 26.0.

RESULTS AND DISCUSSION

Seasonal and depth variation soil properties of each site:

For Site I, notable differences between seasons, particularly with lower pH values during winter and higher values during autumn were reported (Table 2 and 3). The significant variation was also observed in pH levels at all depths (Table 4), with soil moisture content exhibited significant variation across all depths with the highest levels recorded in autumn and the lowest in winter. Similarly, SOC content showed significant variation at all depths being highest during summer and lowest during winter. N_{av} values varied significantly at all depths with diverse seasonal trends observed. Significant variation was also noted in K_{ex} levels among different soil depths with seasonal differences apparent. Similarly, for Site II, significant variation was observed in pH levels at all depths with notable differences between seasons. Soil moisture content exhibited significant variation across all depths with distinct seasonal patterns. SOC content showed significant variation at all depths with varying levels across seasons. N_{av} values showed significant variation at specific depths, with seasonal trends evident. Significant variation was observed in K_{ex} levels at specific

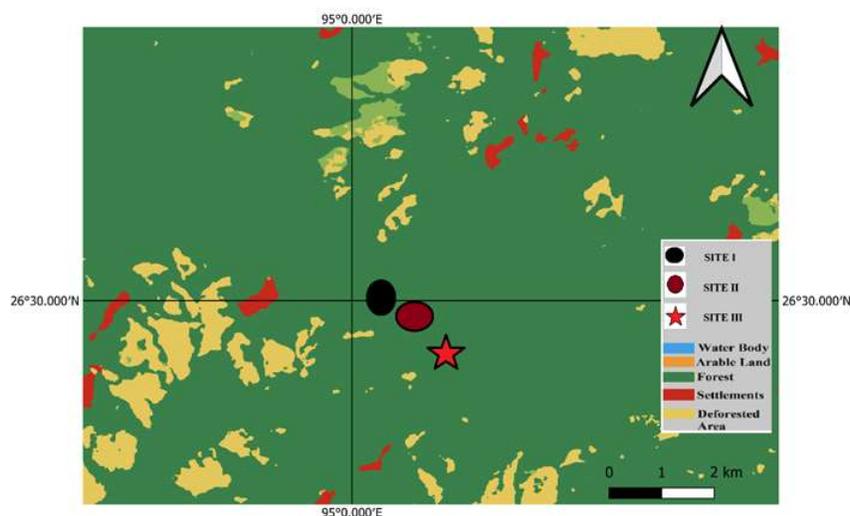


Fig. 1. Land use map of study area displaying the three study sites

Table 1. Soil parameters and its protocol

Method	Parameter measured	Reference
Gravimetric method	Soil moisture	Misra 1968
Pipette method	Clay content	Piper (1942)
Core method	Bulk Density (BD)	Allen (1989)
K ₂ Cr ₂ O ₇ wet oxidation method	Soil Organic Carbon (SOC)	Walkley and Armstrong Black (1934)
KMnO ₄ oxidation method	Available Nitrogen (N _{av})	Kjeldahl (1883) / Kelplus Nitrogen Estimation System
Bray and kurtz method	Available Phosphorus (P _{av})	Bray's No. 1 Extract Method (Bray and Kurtz1945)
Photometric method	Exchangeable Potassium (K _{ex})	Trivedy and Goel (1986)

Table 2. Seasonal variation of soil parameters from the different sites

Site	Season	Soil depth (in cm)	pH	Moisture (%)	SOC (%)	N _{av} (kg ha ⁻¹)	K _{ex} (kg ha ⁻¹)	P _{av} (kg ha ⁻¹)	BD (g cm ⁻³)	Clay (%)	Silt (%)	Sand (%)	Porosity	Particle density
I	Winter	0-10	3.4	36.6	1.81	1434.74	214.77	22.13	1.01	18.56	7.16	74.26	21.80	1.28
		10-20	3.7	34.4	1.45	722.12	64.21	13.76	1.09	16.76	6.73	76.50	29.16	1.52
		20-30	3.7	34.5	0.93	469.63	39.55	11.69	1.20	14.20	9.83	75.96	27.23	1.62
	Spring	0-10	4.7	45.7	2.56	638.04	419.03	19.95	0.87	16.78	9.30	73.91	43.43	1.51
		10-20	4.8	39.2	2.00	525.59	216.72	15.20	1.02	11.07	6.67	82.25	36.06	1.57
		20-30	4.9	37.3	1.73	394.16	201.60	18.49	1.07	10.15	7.69	82.15	27.93	1.50
	Summer	0-10	4.2	45.7	2.93	864.46	306.57	22.23	0.98	17.66	7.83	74.50	38.73	1.62
		10-20	4.4	45.3	2.86	700.54	141.06	14.19	1.06	13.83	5.47	80.70	31.46	1.56
		20-30	4.6	42.2	2.26	359.17	71.99	13.05	1.22	10.47	4.53	84.99	24.36	1.64
	Autumn	0-10	4.8	47.3	2.74	950.98	455.22	29.19	1.08	21.09	10.86	68.04	38.90	1.77
		10-20	5.1	41.1	2.58	875.58	444.17	22.25	1.23	20.93	12.40	66.65	23.23	1.67
		20-30	5.3	36.3	2.37	666.71	293.41	20.31	1.29	14.47	10.89	74.63	17.00	1.56
II	Winter	0-10	3.5	33.4	1.23	1557.33	304.33	20.48	0.80	16.66	10.90	72.36	45.66	1.44
		10-20	3.7	32.9	0.98	783.61	223.24	15.28	0.94	9.46	7.53	83.00	46.20	1.68
		20-30	3.7	28.7	0.66	990.98	198.45	12.70	1.03	10.56	1.93	87.50	43.73	1.80
	Spring	0-10	4.5	44.1	2.00	1297.61	328.10	25.67	0.76	16.59	9.47	73.94	53.06	1.59
		10-20	4.6	38.3	1.6	975.01	194.33	20.94	0.94	9.73	7.56	82.69	37.16	1.49
		20-30	4.6	36.6	1.14	816.27	108.45	13.82	1.02	9.06	5.93	85.00	31.93	1.50
	Summer	0-10	4.4	55.5	2.26	1471.26	381.88	31.62	0.73	14.43	7.56	78.00	63.00	1.97
		10-20	4.4	43.1	2.13	1458.72	221.07	27.01	0.92	14.30	8.25	77.44	50.20	1.86
		20-30	4.3	41.1	2.09	824.85	196.90	21.42	1.17	10.22	3.01	86.77	38.60	1.90
	Autumn	0-10	5.1	46.2	2.33	1008.32	388.07	26.35	0.90	17.31	11.58	71.10	41.43	1.53
		10-20	5.2	40.5	2.27	925.07	250.06	20.21	1.07	12.58	6.25	81.16	23.50	1.58
		20-30	5.3	36.5	2.09	781.04	200.61	16.99	1.16	8.34	3.30	88.34	23.96	1.53
III	Winter	0-10	3.5	31.6	0.92	1632.12	340.14	20.04	6.40	18.41	9.53	72.05	52.13	1.22
		10-20	3.6	30.2	0.83	1105.40	222.61	14.49	0.65	13.07	7.70	79.22	50.03	1.27
		20-30	3.6	28.2	0.80	895.98	169.72	11.66	0.72	10.43	5.66	83.90	55.86	1.69
	Spring	0-10	4.2	42.9	1.06	1325.98	341.34	31.58	0.62	19.17	12.20	68.76	50.76	1.33
		10-20	3.9	39.2	1.03	979.71	166.28	21.18	0.74	12.20	8.26	79.52	46.63	1.39
		20-30	3.8	39.7	1.04	518.90	113.83	14.92	0.89	9.58	2.96	87.45	37.10	1.42
	Summer	0-10	4.3	52.7	1.80	1886.82	440.89	46.78	0.66	20.44	10.54	69.01	66.60	1.98
		10-20	4.5	51.6	1.70	1221.63	216.33	19.22	0.81	14.65	10.92	74.42	56.83	1.88
		20-30	4.6	49.9	1.55	795.57	154.46	16.64	0.98	13.00	8.03	78.96	47.63	1.86
	Autumn	0-10	4.6	45.6	2.11	1168.47	319.49	29.43	0.74	17.70	11.61	70.68	60.76	1.89
		10-20	4.8	38.6	2.02	987.00	200.30	20.01	0.81	12.86	7.39	79.74	61.03	1.81
		20-30	4.9	34.2	1.95	692.33	160.62	17.15	0.96	10.34	3.85	85.80	41.63	1.65

depths with distinct seasonal differences. For Site III, significant variation was observed in pH levels at all depths with seasonal differences. Soil moisture content exhibited

Table 3. The p-values of the seasonal variation of soil parameters from the different sites

Parameters	Soil depth (cm)	Site I	Site II	Site III
		P-value	P-value	P-value
Particle density	0-10	<0.001	.002	<0.001
	10-20	.222	.001	<0.001
	20-30	.544	.002	.007
Porosity	0-10	.150	.095	.139
	10-20	.618	.500	.246
	20-30	.793	.117	.229
Moisture	0-10	<0.001	<0.001	<0.001
	10-20	.001	.002	<0.001
	20-30	.037	.010	<0.001
P _{av}	0-10	.425	.610	.455
	10-20	.365	.528	.527
	20-30	.368	.532	.364
K _{ex}	0-10	<0.001	.002	.006
	10-20	<0.001	.402	.246
	20-30	<0.001	.001	.278
N _{av}	0-10	<0.001	<.001	.001
	10-20	<0.001	.357	.277
	20-30	<0.001	.004	.048
BD	0-10	.425	.610	.530
	10-20	.365	.528	.527
	20-30	.368	.532	.364
SOC	0-10	<0.001	<0.001	.004
	10-20	.015	.001	.003
	20-30	.005	.005	<0.001
Clay	0-10	.193	.581	.164
	10-20	.002	.101	.742
	20-30	.006	.268	.245
pH	0-10	<0.001	.000	<0.001
	10-20	<0.001	.000	<0.001
	20-30	<0.001	.000	<0.001
Silt	0-10	.428	.260	.751
	10-20	.099	.881	.260
	20-30	.040	.206	.202
Sand	0-10	.274	.365	.587
	10-20	.011	.558	.363
	20-30	.016	.418	.202

Bold font indicates a significant result ($p < 0.05$). Soil moisture (Moisture), available phosphorus (P_{av}), exchangeable potassium (K_{ex}), available nitrogen (N_{av}), bulk density (BD), soil organic carbon (SOC), soil clay content (Clay) and soil pH (pH)

significant variation across all depths with varying levels across seasons. Soil Organic Carbon content showed significant variation at all depths, with distinct seasonal patterns. N_{av} values varied significantly, with the highest values reported in summer and lowest in autumn, while no statistical difference was observed in K_{ex} levels. Seasonal variation in P_{av} levels was observed with diverse trends across seasons. Additionally, significant variation was observed in clay, silt, and sand content, with distinct seasonal patterns. Particle density and porosity of the soil exhibited significant variation across seasons and depths, highlighting diverse soil characteristics.

Seasonal variations in soil properties, such as pH, moisture content, and organic carbon, exhibit distinct patterns with higher values observed during warmer seasons due to increased moisture and decomposition activity, while colder seasons show lower values attributed to decreased microbial activity and moisture levels (Table 2). These fluctuations highlight the importance of monitoring soil parameters across seasons to understand their dynamic influence on soil health and nutrient availability (Temjen et al., 2022). Soil pH was highest in site I across all soil depths. The higher soil pH value was at the lower altitude and it decreased with the increase in altitude. This may be due to the organic matter accumulation on the top soil with the increase at higher elevation (Badia et al., 2016). Ramesh et al. (2019) and Kamal et al. (2023) also observed similar trend. The soil moisture did not show any statistical difference among the three sites, but it was slightly higher at Site III, the higher altitude. Griffiths et al. (2009), observed an increase in soil moisture with increasing elevation in the Oregon Cascade Mountains, aligning with the present study. This increased moisture at higher elevation may be due to the slow decomposition of litter on the forest. soil organic carbon (SOC) decreased with increase in elevation, this may also be attributed to the low accumulation of the organic matter at higher altitude which has lower temperature (Sheikh et al., 2009, Amir et al., 2019) observed lower soil organic carbon in higher elevations in forest soil in Garhwal Himalaya. Similar trend was observed by Bangroo et al., (2017) with altitudinal zones ranging from 1800-2500 masl at the Mawer Range Forest, Kupwara District of Jammu & Kashmir. The N_{av}, P_{av} and K_{ex} showed an increased value with the altitude which may be attributed to the slow process of mineralization and decomposition at the higher elevation (Shedayi et al., 2016). The lower zone, site I has a high BD (1.19 g cm³) while the upper zone site III has low BD value (0.65 g cm³). The human activities at the base of the forest may have caused compaction of soil that has led to low Bulk density. With the decrease in organic carbon at different layers of soil, there

was an increase in the soil bulk density at all three sites. The clay and silt particle increased with increase in altitude, Site I < Site II < Site III. The soil samples contain sand, silt, and clay in the following ranges: 70.12-86.90% for sand, 3.54-10.97% for silt, and 9.55-18.93% for clay. These values fall within the ranges reported by Pravin et al. (2013). The soil porosity values were similar Yafei et al. (2022). The increasing trend of the bulk density at Site I is reflected in the porosity of the soil that decreases.

Creation of SQI from MDS: The result of the PCA depicts that PCA corresponding Site I, II and III explained 85.96,

80.45 and 82.36% respectively of the total data variance (Table 5). In Site I: Sand, SOC, BD and N_{av} were retained as MDS. Under Site II: Sand, SOC, N_{av} and porosity, and under Site III: Clay, pH and porosity were retained, respectively. The retention of these MDS at the particular site reflects the most influencing soil factors (Longchar et al., 2023). Workers have similarly isolated such MDS for aiding in soil monitoring activities. Temjen et al., (2022) isolated and created MDS for fallow and Jhum lands under the region and isolated similar soil traits such as SOC and pH from a total soil data set, highlighting the significant role of these soil variables in

Table 4. Depth-wise comparison soil parameters

Soil depth	Sites	pH	Porosity	SOC (%)	Nav (kg ha ⁻¹)	Kex (kg ha ⁻¹)	Pav (kg ha ⁻¹)	Moisture (%)	BD (g cm ⁻³)	Clay (%)	Silt (%)	Sand (%)	Particle density (gm cm ⁻³)
0-10 cm	Site I	4.31a	35.72a	2.51c	972.05a	348.89a	23.37a	46.39a	0.98c	16.25a	8.79a	72.68ab	1.54a
	Site II	4.38a	51.02b	1.90b	1333.63b	350.59a	26.03a	44.83a	0.800b	18.52b	9.87a	73.85b	1.63a
	Site III	4.15a	57.56b	1.45a	1710.60b	360.46a	31.96b	43.21a	0.6575a	18.93b	10.97a	70.12a	1.60a
10-20 cm	Site I	4.51a	29.98a	2.22b	705.95a	222.17a	16.35a	40.02a	1.1025c	15.65b	8.23a	76.52a	1.58a
	Site II	4.44a	50.79a	1.79ab	1073.43a	201.38a	20.86b	38.69a	.969b	11.52a	7.40a	81.07a	1.65a
	Site III	4.18a	53.63a	1.42a	1503.35a	216.53a	18.73ab	39.90a	.7558a	13.20ab	8.57a	78.22a	1.59a
20-30 cm	Site I	4.62a	24.13a	1.82a	472.41a	176.10a	16.23a	37.58a	1.19b	12.32a	7.82b	79.43a	1.58a
	Site II	4.49a	34.55b	1.49a	853.28c	149.65a	15.09a	35.71a	1.09b	9.55b	3.54a	86.90a	1.68a
	Site III	4.25a	45.55c	1.34a	725.69b	151.63a	15.89a	38.02a	.890a	10.83ab	5.13ab	84.03a	1.65a

Values in the same column with different superscripts in their respective soil depth (0-10 cm, 10-20 cm, and 2030 cm) are significantly different at 5% level by Duncan's multiple range test ($p < 0.05$)

Table 5. Principal Component Analysis (PCA) with factor loadings of the different soil parameters

Site	SITE I				SITE II				SITE III		
	PC-1	PC-2	PC-3	PC-4	PC-1	PC-2	PC-3	PC-4	PC-1	PC-2	PC-3
Eigen value	4.62	2.455	2.038	1.198	5.17	2.27	1.14	1.064	6.20	2.56	1.11
% Variance	38.54	20.45	16.79	9.82	43.10	18.92	9.56	8.86	51.67	21.39	9.29
% Cumulative frequency	38.54	59.00	75.98	85.96	43.10	62.02	71.59	80.45	51.67	73.06	82.36
Factor loadings											
K_{ex}	.574	.710			.768	.438			.853		.329
P_{av}	.566	.663			.548	.703			.746	.353	
BD			-.925		-.694			-.446	-.338	.365	-.821
Particle density			.332	.727	-.657		.391				.885
SOC		.905				.913			.664	.589	
N_{av}	.495			-.767			.927		.849		.346
Moisture		.777	.401		.359	.814			.419	.746	
pH		.511		.675	-.337	.766				.890	
Porosity								.897		.307	.884
Clay	.839				.862				.955		
Silt	.875				.817				.765		
Sand	-.972				-.904				-.938		

Bold indicates the highest loaded factors in their respective columns which are retained for minimum data set (MDS). PC-1 (Principal Component one), PC-2 (Principal Component two) and PC-3 (Principal Component three). soil moisture (Moisture), available phosphorus (P_{av}), exchangeable potassium (K_{ex}), available nitrogen (Nav), bulk density (BD), soil organic carbon (SOC), soil clay content (Clay) and soil pH (pH)

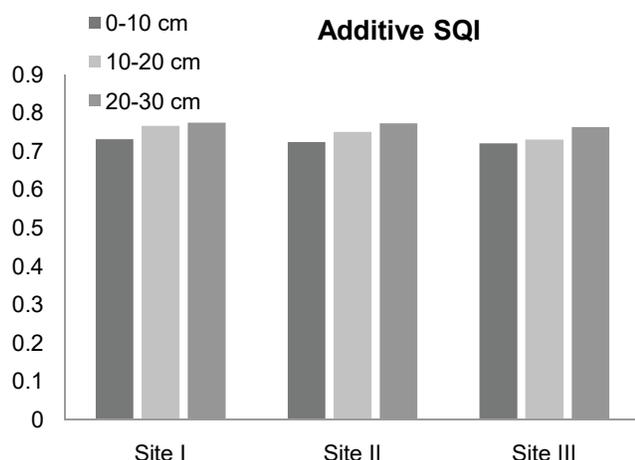


Fig. 2. Additive SQI of the three sites

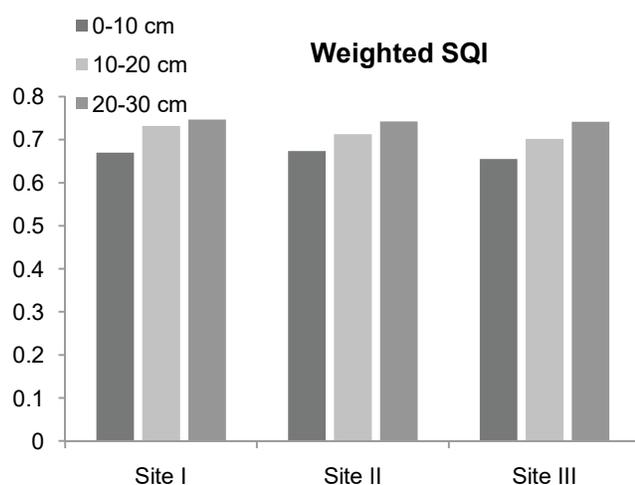


Fig. 3. Weighted SQI of the three sites

determining soil quality. Therefore, the present MDS highlight the distinct soil variable in the region.

The creation of the SQI from the MDS is depicted in Figure 2 and 3. The result of the additive SQI depict soil quality in the order III>II>I and the weighted SQI also depict in the order III>II>I. Mishra et al. (2017), Semy et al. (2021) and Temjen et al. (2022) have used the weighted index owing to its greater accuracy. But in the present study both additive and weighted method give accurate result. The utilization of SQI is effective in reducing both cost and resources associated with monitoring programs (Mamehpour et al., 2021)

CONCLUSION

The study emphasizes the importance of assessing soil quality in forest ecosystems, particularly in Northeast India where forest degradation threatens biodiversity and community livelihoods. Through techniques like Principal

Component Analysis and the development of a Minimum Data Set (MDS), have shown a practical approach to monitoring soil health, crucial for informing sustainable land management. There was distinct seasonal variations in soil properties across different altitudinal zones, highlighting the dynamic nature of soil processes and the need for continuous monitoring. Creating a Soil Quality Index (SQI) from the MDS provides a comprehensive tool for evaluating soil conditions promptly, aiding in effective soil conservation and management. This study fills a research gap by demonstrating the feasibility of SQI techniques in mountainous regions like the Mon district of Nagaland. By enhancing understanding of soil dynamics in challenging terrains, can equip stakeholders and researchers with valuable insights for implementing evidence-based soil conservation strategies. Ultimately, preserving soil quality in forest ecosystems is essential for sustaining biodiversity, ecosystem services, and the livelihoods of indigenous communities. Continued efforts in monitoring soil health and implementing evidence-based management practices are crucial for promoting resilience and sustainability amidst ongoing environmental challenges.

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