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Assessment of Soil Physicochemical Characteristics and NDVI in Response to Forest Vegetation Types of Godawari Kunda Community Forest, Lalitpur, Nepal

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Abstract

This study focused on the relationship between soil physicochemical characteristics and Normalized Difference Vegetation Index (NDVI) in response to forest vegetation types in Godawari Kunda community forest, Lalitpur, Nepal. It aimed to provide valuable interactions of forest ecosystems by investigating how different vegetation types influence soil properties, nutrient cycling, and NDVI. The objectives included assessing soil physicochemical characteristics in response to forest vegetation types and examining NDVI variation across forest types. A stratified random sampling method resulted in 45 plots (10 × 10 m² each) across three altitudinal ranges: *Schima-Castanopsis* forest at the base (1400–1600 m), Mixed Broadleaf forest (1601–1800 m), and Temperate Broadleaf forest (1801–2000 m). The results showed the highest NDVI value (0.75) in the Temperate Broadleaf forest (1801–2000 m), while the lowest NDVI value (0.36) was observed in the *Schima-Castanopsis* forest (1400–1600 m), corresponding to tree density variations. Significant variations in physical and chemical soil characteristics were also evident. Positive correlation was observed between soil organic carbon, available nitrogen and soil moisture with forest vegetation types and NDVI. On the other hand, soil pH and potassium levels showed negative correlations with NDVI and vegetation types. These findings offer valuable data for land-use planning, soil carbon stock assessment, and climate change studies, emphasizing the importance of soil-vegetation relationships for effective ecosystem management, biodiversity conservation, and sustainable land use practices.

Keywords: Mixed Broadleaf forest, NDVI, *Schima-Castanopsis* forest, Soil characteristics, Temperate broadleaf forest

Introduction

Forest ecosystems are constantly changing settings where the relationships between plant life and soil characteristics are crucial for maintaining ecosystem functions and productivity. These relationships are additionally affected by elevation, which determines climate patterns, the distribution of vegetation, and the formation of soil (Banday et al., 2019; Imran et al., 2021). The physicochemical properties of soil, including pH, texture, organic carbon, nitrogen, and potassium, are crucial for the growth of plants and the stability of ecosystems. Changes in these soil characteristics can affect species diversity, nutrient cycling, and the overall health of forests (Dahal et al., 2018; Schoonover & Crim, 2015). Remote sensing technologies, especially the Normalized Difference Vegetation Index (NDVI), are essential tools for evaluating vegetation cover, biomass, and photosynthetic processes. NDVI measures spectral reflectance in the red and near-infrared wavelengths to assess the health of vegetation, with higher NDVI readings reflecting lush, thriving vegetation and lower readings indicating sparse or degraded cover (Tucker, 1979; Yacouba et al., 2010). In mountain ecosystems, variations in altitude lead to diverse types of vegetation, which often correlate with alterations in soil characteristics and NDVI values (Banday et al., 2019; Imran et al., 2021). Analyzing the variations of NDVI among various forest types and altitude levels can offer valuable information regarding vegetation productivity, land cover changes, and overall ecosystem health.

The Godawari Kunda community forest is located in the Godawari Municipality within the Lalitpur district, positioned on the southern inclines of Phulchowki Hill in central Nepal (27°352 07.473 N, 85°242 05.183 E). This area ranges in elevation from 1400 to 2000 meters above sea level (asl) and serves as a transitional zone between subtropical and temperate climate regions (Kharbuja & Rajbhandary, 2022). The forest consists of three primary types of vegetation-*Schima-Castanopsis* forest in the lower regions, Mixed Broadleaf forest in the middle regions, and Temperate Broadleaf forest in the upper regions. Godawari and Phulchowki are noted as important biodiversity hotspots in Nepal, hosting a variety of plant and animal life, including species that are endemic and at risk. Although the ecological and conservation importance is recognized, there are few integrated studies that investigate the connection between soil physicochemical properties, types of forest vegetation, and remotely sensed NDVI data in this region. However, this research intends to evaluate how different types of forest vegetation affect the physicochemical properties of soil and NDVI in the Godawari Kunda community forest located in Nepal. The specific objectives include to assess the variation in NDVI, evaluating the soil physical and chemical characteristics in response to forest vegetation types of Godawari Kunda community forest.

Material and Methods

Study area

The study has been carried out, in Godawari Kunda community forest which is situated in Godawari Municipality, Phulchowki hill, Lalitpur district of Bagmati zone, Nepal (27°35' 07.47"N, 85°24'05.18"E) (Figure 1). Phulchoki Hill is located in the area where the subtropical and temperate climates meet in the southern Kathmandu Valley (Kharbuja & Rajbhandary, 2022). The altitude of Godawari Kunda community forest hill ranges from 1400 to 2006 m asl.

The study site is located inside the territory of Phulchowki Hill and three different types of evergreen broad-leaved forests make up Godawari Kunda community forest vegetation[a *Schima-Castanopsis* forest at the base (1400 m to 1600 m), Mixed broadleaf forest (1600 m to 1800 m), and Temperate Broadleaf forest (1800-2000 m)].

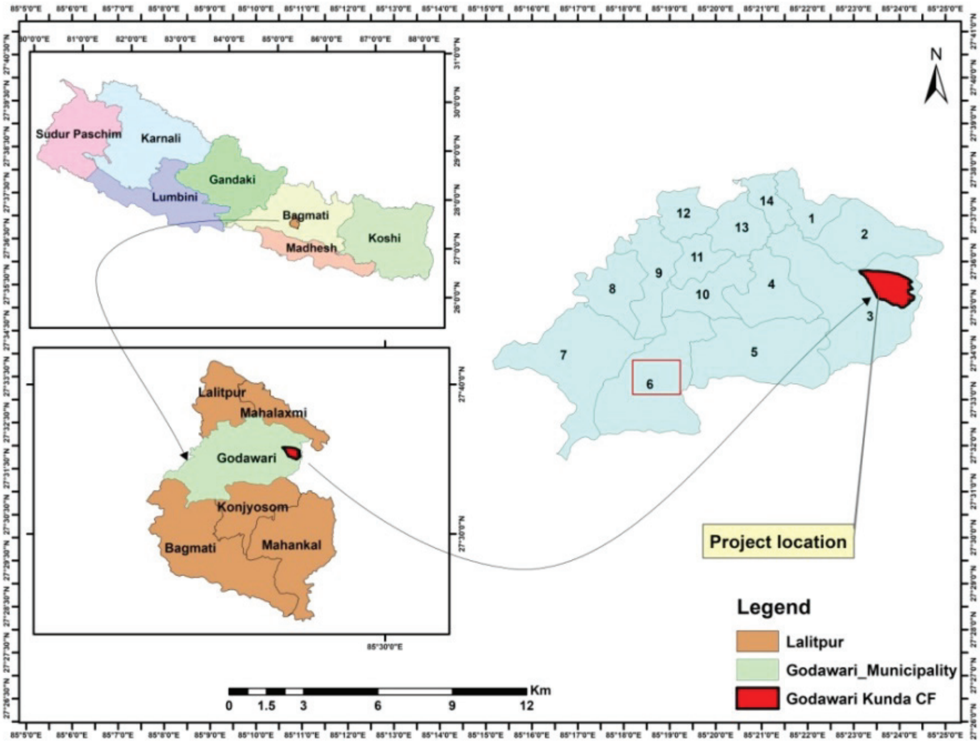

Figure 1: Study site

Field visits and soil sample collection

A stratified random sampling approach was employed to investigate the physicochemical properties of soil across three types of forest vegetation: *Schima-Castanopsis* (1400-1600 m), Mixed Broadleaf (1601-1800 m), and Temperate Broadleaf (1801-2000 m). For each stratum, 15 plots measuring 10 × 10 m were established through a randomized block design, culminating in a total of 45 plots. Soil samples were taken from two different depths (0-15 cm and 15-30 cm) with the help of a soil borer and shovel. The sampling was conducted in triplicate for every depth and forest type, leading to a total of 90 composite soil samples. Each sample was placed in a labeled polythene bag, and the fresh weight was measured on-site using a portable digital scale. GPS coordinates and aspect details were noted for all plots.

Laboratory analysis of soil parameters

Soil pH was assessed with a digital pH meter in a 1:2.5 mixture of soil and water (Jackson, 1973). The soil texture, including sand, silt, and clay, was analyzed using the hydrometer method (Bouyoucos, 1962). The organic carbon content was determined through the Walkley-Black dichromate oxidation procedure (Walkley & Black, 1934). Total nitrogen levels were quantified using the Kjeldahl digestion technique (Bremner & Mulvaney, 1982), while available potassium was measured through flame photometry after extraction with ammonium acetate (Jackson, 1973). Moisture content was calculated gravimetrically by drying fresh samples at 105°C for at a duration of 24 hours.

Laboratory tests for organic matter and carbon were performed at the SchEMS College Environmental Laboratory, while the analyses for nitrogen and potassium were conducted at the Laboratory of Department of Environmental Science, Tribhuvan University, Kathmandu.

NDVI data acquisition and processing

NDVI values were obtained from Sentinel-2A multispectral satellite images with a resolution of 10 m, accessed through the Copernicus Open Access Hub for the years 2017 and 2022. The pre-processing phase involved atmospheric correction via the Sen2Cor plugin in SNAP software. NDVI was computed using the conventional formula:

$$NDVI = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}$$

Where, NIR and RED refer to the near-infrared (Band 8) and red (Band 4) bands, respectively. NDVI maps and classification were generated using QGIS 3.10

Data analysis

Statistical analyses were conducted using SPSS (version 20) and Microsoft Excel. Descriptive statistics were used to summarize the data. To assess differences among forest types, one-way ANOVA was performed for normally distributed variables, with Tukey's B post-hoc test for pair wise comparisons. For non-normally distributed data, the Kruskal-Wallis H test was used. Significant differences were considered at $p < 0.05$. Correlation analysis (Pearson's r) was conducted to examine relationships between NDVI and soil parameters. The significance of differences in soil parameters across depth and forest type was further interpreted based on F-values (ANOVA) and χ^2 values (Kruskal-Wallis), as detailed in the results section.

Results and Discussion

The physicochemical properties of soil showed considerable variation among the three types of forest vegetation and different soil depths in the Godawari Kunda community forest. The analyzed parameters included soil texture, moisture levels, pH, organic carbon (OC), total nitrogen (N), available potassium (K), phosphorus (P), and NDVI. Statistical tests (ANOVA, Kruskal-Wallis) indicated significant differences in most parameters across the forest types ($p < 0.05$), especially in NDVI, soil moisture, organic carbon, nitrogen, and phosphorus.

NDVI variation and tree density

NDVI values were highest in the Temperate Broadleaf forest (mean NDVI = 0.75), followed by the Mixed Broadleaf forest (0.52), and lowest in the *Schima-Castanopsis* forest (0.36) (Figure 2). One-way ANOVA revealed a statistically significant difference in NDVI values among the three forest types ($F(2,42)$, $p< 0.001$), indicating that vegetation greenness significantly varies with forest type.

The higher NDVI values observed in upper elevation forests correspond with greater tree density and enhanced soil fertility. This pattern supports previous research by Banday et al. (2019) and Imtimongla et al.(2021), which reported increased canopy vigor and vegetation density at higher elevations. Pearson correlation analysis further demonstrated that NDVI is significantly and positively correlated with organic carbon (r = 0.79), nitrogen (r = 0.74), and soil moisture (r = 0.68), while it is negatively correlated with soil pH (r = -0.62) and potassium (r = -0.57), all of which were statistically significant ($p< 0.01$).

In terms of forest structure, the highest tree density was recorded in the Temperate Broadleaf forest located at elevations between 1801-2000 m, where tree height ranged from 10.1 to 20 meters. This forest type contained 340 trees per hectare, significantly higher than the densities observed in other forest types ($p< 0.05$, Tukey HSD post-hoc test). Conversely, the *Schima-Castanopsis* forest, located at lower elevations (1400–1600 m), exhibited the lowest tree density, with only 100 trees per hectare and dominant tree heights ranging from 20.1 to 30 meters (Figure 3).

These findings indicate a statistically significant variation in tree density across forest types, which is consistent with the NDVI distribution observed

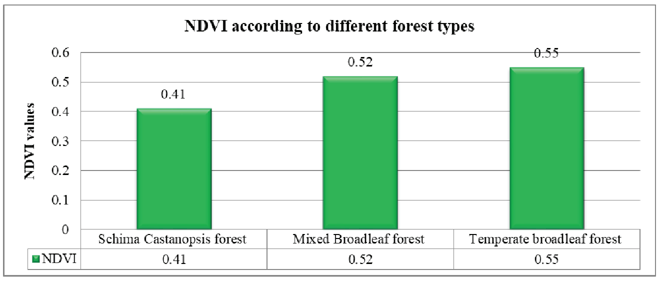

Figure 2: NDVI values according to different forest types

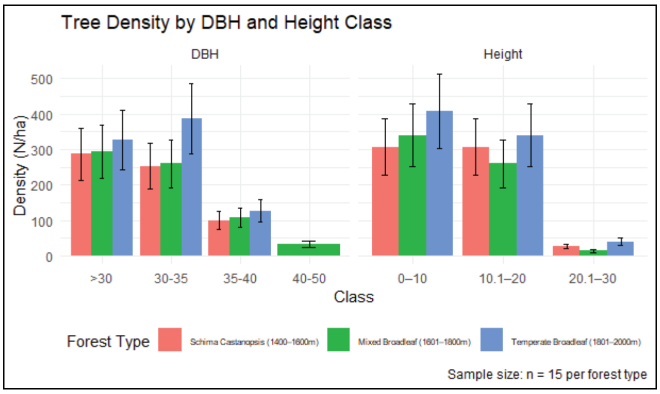

Figure 3: Density of the forest according to forest vegetation types

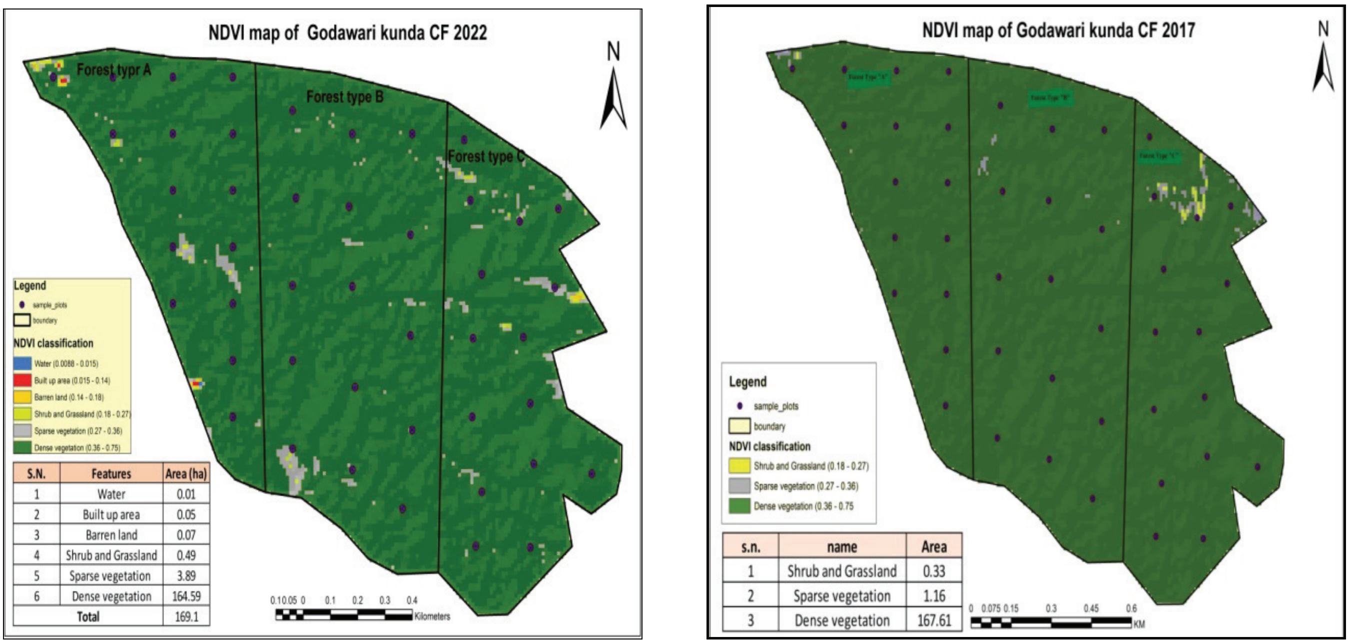

Figure 4: NDVI maps of Godawari Kunda community forest in year 2017 and 2022

in Sentinel-2A imagery (Figure 4). The strong association between NDVI and tree density suggests that NDVI can be a reliable proxy for assessing vegetation structure and forest health in the study area.

Physical properties

Soil texture: Soil texture displayed slight yet consistent changes along elevation gradients. Soils of the *Schima-Castanopsis* forest (1400-1600 m) possessed the greatest sand content (94.33%) along with the least clay content (3.73% at 0-15 cm), reflecting a coarser texture with reduced capacity for holding water. Conversely, the Temperate Broadleaf forest (1801-2000 m) had the highest clay content (5.2% at 15-30 cm) and the lowest sand content (92.2%), which enhances its ability to retain moisture (Table 1, Figure 5).

Moisture: Moisture levels rose notably with elevation at both soil depths. In the upper layer (0-15 cm), the average soil moisture recorded was 22.65% in the *Schima-Castanopsis* forest, 42.20% in the Mixed Broadleaf forest, and 58.15% in the Temperate Broadleaf forest. For the deeper layer (15-30 cm), the corresponding moisture percentages were 17.74%, 36.72%, and 52.12%, respectively (Table 2, Figure 6). Statistical evaluations indicated significant differences in moisture content among the various forest types ($F(2,42) = 89.854$ for 0-15 cm; $F(2,42) = 91.704$ for 15-30 cm; $p < 0.001$). The elevated moisture levels in higher elevation forests foster microbial activity and the breakdown of organic matter, which facilitates nutrient cycling and accumulation (Imtimongla et al., 2021).

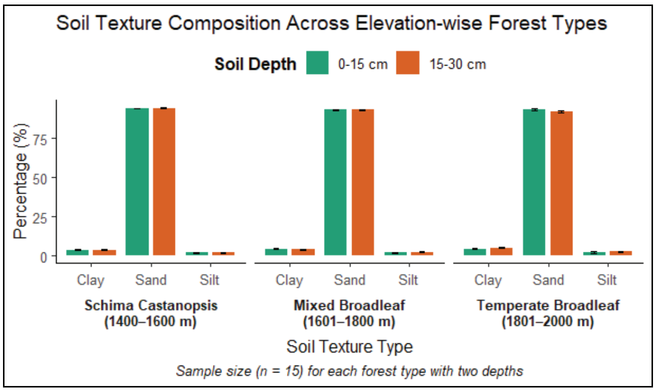

Figure 5: Clay, slit and sand content in soil response to forest vegetation types

Table 1: Descriptive statistics of clay, slit and sand content in soil response to forest vegetation types

Forest Types	Soil Texture	Descriptive Statistics							
		Soil depth (0-15 cm)				Soil depth (15-30cm)			
		Mean±SE	SD	Min.	Max	Mean±SE	SD	Min.	Max
Schima-Castanopsis forest (1400-1600m)	Silt	1.93±0.25	0.98	0.5	3	2±0.25	0.98	0	4
	Clay	3.73±0.18	0.73	2.3	4.3	3.67±0.26	1.008	2.3	5.3
	Sand	94.33±0.27	1.04	92.7	96.7	94.33±0.38	1.47	92.7	97.7
Mixed Broadleaf forest (1601-1800 m)	Silt	2±0.29	1.15	1	4.5	2.53±0.45	1.74	0	7
	Clay	4.5±0.29	1.105	2.6	6.1	4.167±0.35	1.35	2.1	6.6
	Sand	93.5±0.39	1.54	89.4	95.4	93.3±0.54	2.09	89.4	97.4
Temperate Broadleaf forest (1801-2000 m)	Silt	2.167±0.52	2.023	0	6	2.6±0.55	2.13	0.5	8
	Clay	4.5±0.20	0.78	3.1	5.6	5.2±0.19	0.74	4.1	6.6
	Sand	93.33±0.64	2.49	88.4	96.4	92.2±0.68	2.62	85.4	95.4

Table 2: Descriptive statistics of moisture content (%) in soil in response to forest vegetation types

Forest Types	Descriptive Statistics							
	Soil depth (0-15 cm)				Soil depth (15-30 cm)			
	Mean±SE	SD	Min	Max	Mean±SE	SD	Min	Max
Schima-Castanopsis forest (1400-1600 m)	22.65±2.02	7.82	11	33.33	17.74±1.79	6.73	8.1	29.03
Mixed Broadleaf forest (1601-1800 m)	42.20±1.9	7.39	29.03	53.85	36.72±1.86	7.21	25	48.14
Temperate Broadleaf forest (1801-2000 m)	58.15±1.69	6.53	48.14	66.67	52.12±1.56	6.04	42.86	60

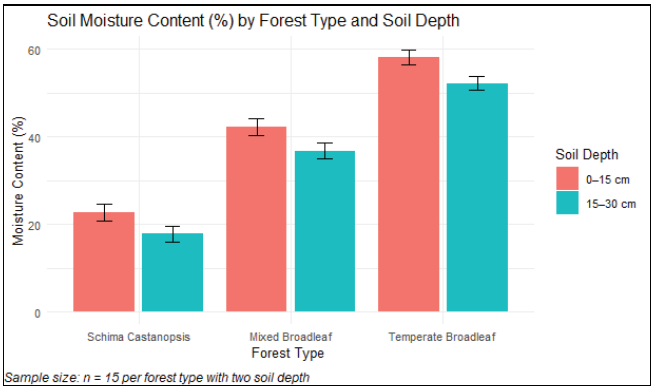

Figure 6: Moisture content (%) in soil in response to forest vegetation types

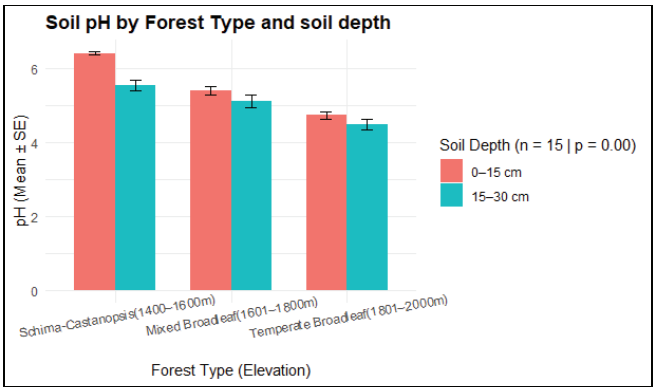

Figure 7: Difference in pH in different forest types

Chemical properties

pH: Soil pH was found to decline as altitude increased, with values ranging from 6.7 in the *Schima-Castanopsis* forest to 4.49 in the Temperate Broadleaf forest (Table 3, Figure7). Significant differences were identified among different forest types and soil depths through ANOVA and Kruskal-Wallis tests (F (2,42) = 11.115 at 0-15 cm, $\chi2(2)$ = 18.219 at 15-30 cm; $p < 0.001$). The reduction in pH is linked to the accumulation of organic matter and leaching processes occurring at higher elevations (Tellen& Yerima, 2018).

Organic carbon, nitrogen, potassium and phosphorous: The content of organic carbon and nitrogen increased with altitude. The highest level of OC was found in the Temperate Broadleaf forest (3.99% at 0-15 cm), with notable differences observed among various forest types (F(2,42) = 15.580 at 0-15 cm; F(2,42) = 26.141 at 15-30 cm; $p < 0.001$). A similar pattern was observed for nitrogen content, which peaked in the upper forest (F(2,42) = 15.580 at 0-15 cm; F(2,42) = 26.141 at 15-30 cm; $p < 0.001$). These findings are consistent with those of Banday et al.(2019) and Shelukindo et al.(2014), who found elevated levels of SOC and N in cooler, less disturbed forests that have abundant litter input.

Table 3: Descriptive statistics of chemical properties in response to forest vegetation types

Chemical Properties	Forest Types*	Descriptive Statistics							
		Soil depth (0-15 cm)				Soil depth (15-30cm)			
		Mean±SE	SD	Min.	Max	Mean±SE	SD	Min.	Max
pH	A	6.4±0.044	0.173	6.2	6.7	5.54±0.153	0.59	4.3	6.3
	B	5.4±0.128	0.49	4.4	6.2	5.11±0.176	0.68	3.6	6
	C	4.73±0.106	0.412	4.1	5.3	4.49±0.146	0.56	3.7	5.3
OC	A	2.52±0.24	0.92	0.77	4.27	1.75±0.19	0.74	0.39	3.11
	B	2.63±0.24	0.93	0.78	3.69	1.98±0.22	0.84	0.39	3.30
	C	3.99±0.13	0.49	3.11	4.66	3.54±0.16	0.61	2.72	4.66
N	A	0.43±0.04	0.16	0.134	0.74	0.302±0.03	0.13	0.067	0.536
	B	0.45±0.04	0.16	0.134	0.64	0.34±0.04	0.14	0.067	0.57
	C	0.69±0.022	0.08	0.536	0.804	0.609± 0.027	0.11	0.469	0.804
P	A	14.56±0.52	2.03	12.11	17.85	13.50±0.59	2.28	10.21	17.43
	B	18.73±1.19	4.59	11.39	26.71	16.87±1.12	4.36	10.17	26.21
	C	21.21±0.91	3.53	16.67	26.16	20.23±0.92	3.57	15.66	25.07
K	A	411.98±74.51	288.57	217.73	1306.37	302.67±19.99	77.43	193.54	502.66
	B	323.81±26.91	104.22	209.66	545.66	308.76±23.63	91.52	215.04	532.22
	C	328.65± 26.94	104.33	137.088	567.17	298.55±21.36	82.71	139.78	405.89

*Note: *Schima-Castanopsis* forest (1400-1600m), Mixed Broadleaf forest (1601-1800 m), Temperate Broadleaf forest (1801-2000 m) are referred as Forest type 'A', 'B' and 'C'

The levels of available potassium did not exhibit notable differences across various forest types (Kruskal-Wallis $\chi2(2) = 0.418$ at 0-15 cm; $\chi2(2) = 0.000$ at 15-30 cm; $p > 0.05$). This lack of variation may be attributed to a consistent parent material or a stable mineral composition (Imran et al., 2021). On the other hand, phosphorus exhibited significant variability among forest types ($F(2,42) = 13.442$ at 0-15 cm; $F(2,42) = 13.752$ at 15-30 cm; $p < 0.001$), indicating its susceptibility to biological cycling and the effects of forest management strategies (Kidanemariam et al., 2012).

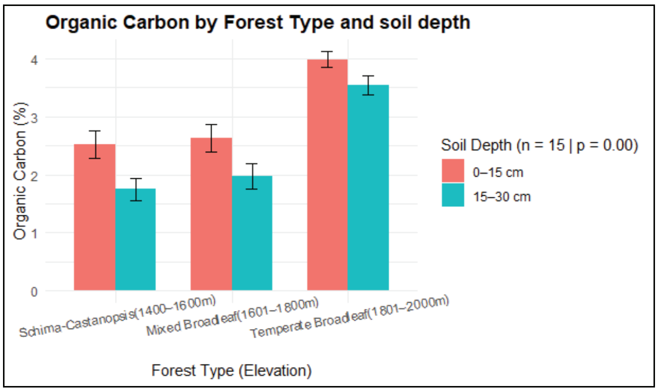

Figure 8: Difference in organic carbon in different forest types

Within the temperate broadleaf forest (1801-2000 m), the organic carbon content reached its peak at 4.66% in the 0-15 cm and 15-30 cm depth, while the lowest content of 0.39% was observed in the 15-30 cm depth of the Mixed Broadleaf forest (1601-1800 m) and *Schima-Castanopsis* forest (1400-1600 m) (Table 3, Figure 8).With rising altitudinal ranges, the organic carbon content rose (Banday et al., 2019) given reason that the persistent accumulation of leaf litter and the slower decomposition rate caused by the lower temperature can be attributed to the larger levels of organic carbon in higher altitudes. Higher elevations will have more organic carbon content because slower breakdown can result in less mineralization and less erosion of organic carbon. Also, seen in the result of research done by Shelukindo et al. (2014) that compared to the relatively lower elevation, the relatively higher elevation conditions encouraged significantly more SOC buildup.

In Godawari Kunda community forest, it has been observed that potassium exhibits a negative correlation with various types of forest vegetation. Among the different forest types, the *Schima-Castanopsis* forest (1400-1600 m) showed the highest potassium level at a soil depth of 0-15 cm, measuring 1306.37 kg/ha. On the other hand, the Temperate Broadleaf forest (1801-2000m) had the lowest potassium content, with a measurement of 137.088 kg/ha at the 0-15 cm soil depth (Table 3, Figure 9). It may be because of altitude influencing the type and composition of rocks and minerals in an area. Some rocks contain potassium-bearing minerals. However, at higher altitudes, the types of rocks present may be less likely to contain significant amounts of potassium-rich minerals. This limited availability of potassium-bearing minerals can contribute to lower potassium levels in the soil (Imran et al., 2021).

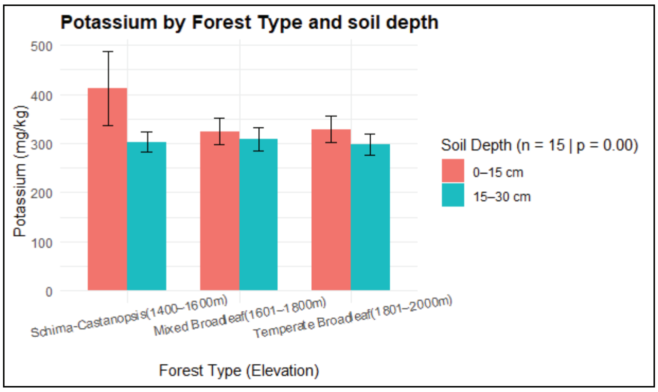

Figure 9: Difference in content of potassium in different forest types

The results of the nitrogen content analysis in the soil revealed varying levels among different forest types at different altitudes. The highest nitrogen content, measuring 0.804%, was observed in the Temperate Broadleaf forest located between 1801-2000 meters above sea level. On the other hand, the lowest nitrogen content, measuring 0.067%, was found in both the *Schima-Castanopsis* forest (1400-1600m) and Mixed Broadleaf forest (1601-1800m) (Table 3, Figure 10). These measurements were taken at a soil depth of 0-15 and 15-30 centimeters. It was found that the amount of nitrogen content increased with increase in response to forest vegetation. Therefore, with rising NDVIs, the amount of available N, P, K, Ca, and S increased (Banday et al., 2019). Same result was observed by Imtimongla et al.(2021), high SOM may be the cause of the soil's high total N concentration with elevation.

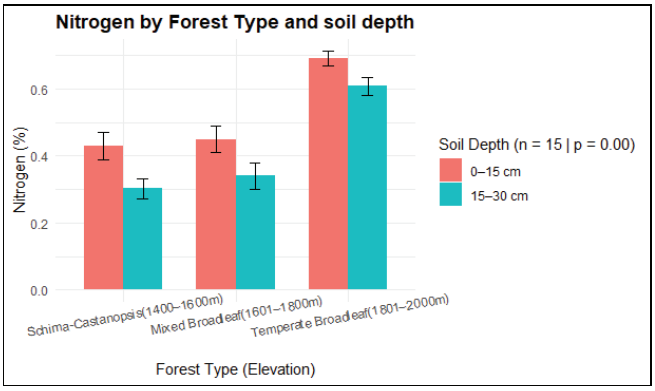

Figure 10: Difference in nitrogen content in different forest types

The analysis of available phosphorus in the soil across different forest types and altitudes revealed a clear variation. The highest phosphorus content was recorded in Temperate Broadleaf forest with a mean value of 21.21 ± 0.91 mg/kg at 0-15 cm depth and 20.23 ± 0.92 mg/kg at 15-30 cm depth. In contrast, the lowest phosphorus concentration was found in *Schima-Castanopsis* forest, measuring 14.56 ± 0.52 mg/kg at 0-15 cm and 13.50 ± 0.59 mg/kg at 15-30 cm. (Mixed Broadleaf forest showed intermediate phosphorus levels (Table 3, Figure 11). The trend of increasing phosphorus with elevation and forest type can be attributed to higher organic matter accumulation and nutrient cycling efficiency in upper elevation forests. These results are consistent with the findings of Banday et al. (2019), who

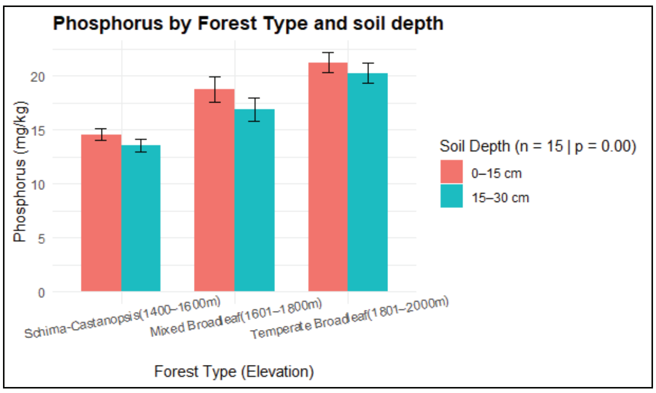

Figure 11: Difference in phosphorous content in different forest types

reported that available phosphorus content tends to increase with higher NDVI and forest productivity. Similarly, Imtimongla et al.(2021) observed elevated phosphorus levels in soils with higher soil organic matter (SOM) at greater altitudes, suggesting improved mineralization and nutrient retention capacity. The current findings support the notion that phosphorus availability is closely linked to vegetation type and altitudinal gradients.

Conclusion

This research reveals that different types of forest vegetation and variations in altitude significantly affect the physicochemical properties of soil and the health of vegetation, as measured by NDVI, within the Godawari Kunda community forest. The Temperate Broadleaf forest, located at the highest altitude, displayed notably elevated levels of NDVI, soil organic carbon, total nitrogen, and moisture, along with reduced pH levels in comparison to forests at lower elevations. These observed trends indicate a greater accumulation of nutrients, increased vegetation density, and enhanced ecological interactions in high-altitude forest systems that are less disturbed.

Statistical evaluations (ANOVA, Kruskal-Wallis, and correlation) demonstrated that the majority of soil characteristics varied considerably across different forest types, with phosphorus exhibiting significant variation while potassium remained relatively unchanged. NDVI showed a strong positive correlation with essential fertility indicators (OC, N & moisture), reinforcing its usefulness as a remote sensing tool for evaluating forest health and soil quality. The combination of satellite-derived NDVI and field-based soil analyses creates a strong framework for monitoring forest ecosystems, especially within mountainous and community-managed landscapes.

By establishing foundational connections between vegetation type, altitude, soil fertility, and NDVI, this study provides valuable insights for sustainable forest management, land-use planning, and ecosystem monitoring in the mid-hill regions of Nepal. It also emphasizes the importance of merging field ecology with geospatial methodologies for assessments at the landscape level in regions rich in biodiversity but lacking extensive data.

Author Contributions

B Timilsina & P K Regmi have contributed equally to bring the manuscript in this form and R A Mandal designed the research.

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