Article

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APPLICATION OF VEGETATION INDEXES TO ASSESS CARBON STOCK

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Abstract

This was objectively conducted to estimate the carbon stock, to show the relation between carbon stock and indices and to assess the factors affecting carbon stock in community forests. Three community forests (CFs) namely Gumalchowki, Mahakalsthan and Mahalaxmi of Chandragiri Municipality in Nepal were selected as research sites. Altogether 135 plots were randomly established to collect data from the field. The biomass was calculated using Chave et al., equation which was converted into carbon stock multiplying by default value 0.47. The values of Normalized Difference Vegetation Index (NDVI), Difference Vegetation Index (DVI) and Infrared Percentage Vegetation Index (IPVI) were calculated and regression equation between the indices and carbon stock was performed. The result showed that total above ground carbon stock was highest in Mahalaxmi CF with 30.42 ton/ha, followed by Mahakalsthan CF with 22.62 ton/ha and comparatively lowest with 21.55 ton/ha in Gumalchowki CF. The regression analysis between carbon stock and indices showed significantly and positive correlation. The R2 value of NDVI of Gumalchowki, Mahakalsthan and Mahalaxmi CF were found to be 0.51, 0.54 and 0.58, also, RMSE value of CFs were 1.41, 1.36 and 1.91 respectively. Principal component analysis showed that road construction, transmission line expansion, soil erosion, encroachment, disease, weeds, recreation, illegal logging are the major factors affecting carbon stock in all three community forests.

Keywords: Carbon, Nepal, Community Forests.

Resumo / Résumé

APLICAÇÃO DE ÍNDICES DE VEGETAÇÃO PARA AVALIAR O ESTOQUE DE CARBONO

O presente trabalho foi conduzido objetivamente para estimar o estoque de carbono, mostrar a relação entre seu estoque e índices, bem como avaliar os fatores a afetarem seu estoque nas florestas comunitárias. Três florestas comunitárias (CFs), nomeadamente Gumalchowki, Mahakalsthan e Mahalaxmi do município de Chandragiri no Nepal, foram selecionadas. Ao todo 135 parcelas foram estabelecidas aleatoriamente para coletar dados de campo. A biomassa foi calculada usando Chave et al., equação que foi convertida em estoque de carbono multiplicando pelo valor padrão 0,47. Os valores do Índice de Vegetação por Diferença Normalizada (NDVI), Índice de Vegetação por Diferença (DVI) e Índice de Vegetação Porcentual de Infravermelho (IPVI) foram calculados e a equação de regressão entre os índices e o estoque de carbono foi realizada. O resultado mostrou que o estoque total de carbono acima do solo foi maior em Mahalaxmi CF com 30,42 ton/ha, seguido por Mahakalsthan CF com 22,62 ton/ha e comparativamente mais baixo com 21,55 ton/ha em Gumalchowki CF. A análise de regressão entre estoque de carbono e índices mostrou correlação significativa e positiva. O valor R2 de NDVI de Gumalchowki, Mahakalsthan e Mahalaxmi CF foi de 0,51, 0,54 e 0,58, também, o valor de RMSE de CFs foi de 1,41, 1,36 e 1,91, respectivamente. A análise de componentes principais mostrou que a construção de estradas, expansão da linha de transmissão, erosão do solo, invasão, doenças, ervas daninhas, recreação, extração ilegal de madeira são os principais fatores que afetam o estoque de carbono em todas as três florestas comunitárias.

Palavras-chave: Carbono, Nepal, Florestas Comunitárias.

APLICACIÓN DE ÍNDICES DE VEGETACIÓN PARA EVALUAR LAS EXISTENCIAS DE CARBONO

La rechehche a été réalisé objectivement pour estimer le stock de carbone, pour montrer la relation entre son stock et les indices et pour évaluer les facteurs affectant le stock de carbone dans les forêts communautaires. Trois forêts communautaires (CF) à savoir Gumalchowki, Mahakalsthan et Mahalaxmi de la municipalité de Chandragiri au Népal ont été sélectionnées comme sites de recherche. Au total, 135 parcelles ont été établies au hasard pour recueillir des données sur le terrain. La biomasse a été calculée à l'aide de Chave et al., équation qui a été convertie en stock de carbone en multipliant par défaut la valeur 0,47. Les valeurs de l'indice de végétation par différence normalisée (NDVI), de l'indice de végétation par différence (DVI) et de l'indice de végétation en pourcentage dans l'infrarouge (IPVI) ont été calculées et l'équation de régression entre les indices et le stock de carbone a été réalisée. Le résultat a montré que le stock total de carbone au-dessus du sol était le plus élevé à Mahalaxmi CF avec 30,42 tonnes/ha, suivi par Mahakalsthan CF avec 22,62 tonnes/ha et comparativement le plus bas avec 21,55 tonnes/ha à Gumalchowki CF. L'analyse de régression entre le stock de carbone et les indices a montré une corrélation significative et positive. La valeur R2 du NDVI de Gumalchowki, Mahakalsthan et Mahalaxmi CF s'est avérée être de 0,51, 0,54 et 0,58, également, la valeur RMSE des FC était de 1,41, 1,36 et 1,91 respectivement. L'analyse en composantes principales a montré que la construction de routes, l'expansion de la ligne de transmission, l'érosion des sols, l'empiètement, les maladies, les mauvaises herbes, les loisirs, l'exploitation forestière illégale sont les principaux facteurs affectant le stock de carbone dans les trois forêts communautaires.

Mots-clés: Carbone, Nepal, Forêts Communautaires.

INTRODUCTION

The methodology and approach is very important to monitor and evaluate the forest carbon (Smith et al., 2008, Soenen et al., 2010). The higher the crown density the higher is the reflectance value. It is obvious fact that higher crown density is the indicator of higher biomass and carbon. Thus, the reflectance of crown which is captured as data in remote sensing is useful tools to evaluate forest carbon (Näsi et al., 2015, Cui et al., 2019). The forest carbon is accredited as carbon credit under REDD+ mechanism. The forest is carbon is contributing to minimize the impact of climate (Palmer, 2011). As billions of people are benefitted from the forest and forest ecosystem, the benefits can be simply classified into tangible and intangible benefits. The tangible benefits are timber, firewood, fodder, litter, medicines while the intangible benefits are soil conservation, fertility, water restoration. Millions of industries are based on the tangible products which have been supporting the livelihood promotion of the local people. The carbon sequestration is one of the important intangible benefits of the forest (Gunawardena et al., 2020).

The carbon sequestration is playing a vital role to minimize the impact of climate change thus Reducing emission from deforestation and forest degradation (REDD) mechanism becoming popular especially in developing countries where the deforestation and forest degradation is very high (Asner et al., 2010, Bhandari, 2012, Cao et al., 2012), 1 tons of carbon stored in trees is the result of the removal of 3.67 tons of carbon dioxide from the atmosphere. More than eighty countries are working with REDD+ mechanism in the world (Mandal et al., 2017, Amir et al., 2018). This phase is considered as the performance based payment phase under REDD+ mechanism which requires the REDD+ strategies, Monitoring Reporting and Verification and reference emission level (Mandal et al., 2016, Zhong et al., 2017, Sharma & Kakchapati, 2018. These reports emphasize on the requirement of reliable method of monitoring of the carbon.

The remote sensing (RS) techniques have gained wide spread acceptance for vegetation mapping and monitoring (Ingram et al., 2005; Lu et al., 2004; Maynard et al., 2007) which measures the spectral reflectance of the vegetation (Zianis et al., 2005). In several research, satellite-based vegetation indices (VIs) models are the most often used models for biomass estimation (Foody et al., 2003; Schlerf et al., 2005; Zheng et al., 2004). Many previous studies have discovered significantly positive strong relationship between biomass and vegetation indices (Steininger, 2000; Zheng et al., 2004, Maynard et al., 2007). Similarly, research done in Savannakhet Province, Lao PDR showed the significant correlation between the above ground biomass (AGB) and spectral reflectance value of different indices (Vicharnakorn et al., 2014). However, these types of researches are very limit in Nepal. Thus, this study was conducted to estimate the carbon stock and show its correlation with the reflectance value of indices and also factors affecting on carbon stock in community forests.

MATERIALS AND METHODOLOGY

RESEARCH SITE

Kathmandu district is situated between 27.700769° N latitude and 85.300140° E longitude in the hilly region of Bagmati Province in the central part of Nepal. It is oval shaped intermountain basin which stretches at about 30 km in East-West and 25 km in North-South direction and occupies about 650 sq.km and elevation ranges from 1220 to 1500m. The average temperature and rainfall are 16.1˚C and 1343 mm per annum respectively. Chandragiri Municipality situated in south-west part of Kathmandu valley in Bagmati Province. Total area of the municipality is 43.92 sq.km. The chosen Gumalchowki, Mahakalsthan and Mahalaxmi CFs are 1400m to 2580m above from the sea level. Mainly, Katus (Castanopsis indica), Chilauni (Schima wallichii), Salla (Pinus roxburghii), Uttis (Alnus nepalensis), Khasru (Quercus semecarpifolia), Kafal (Myrica esculenta) are the major tree species of these forests.

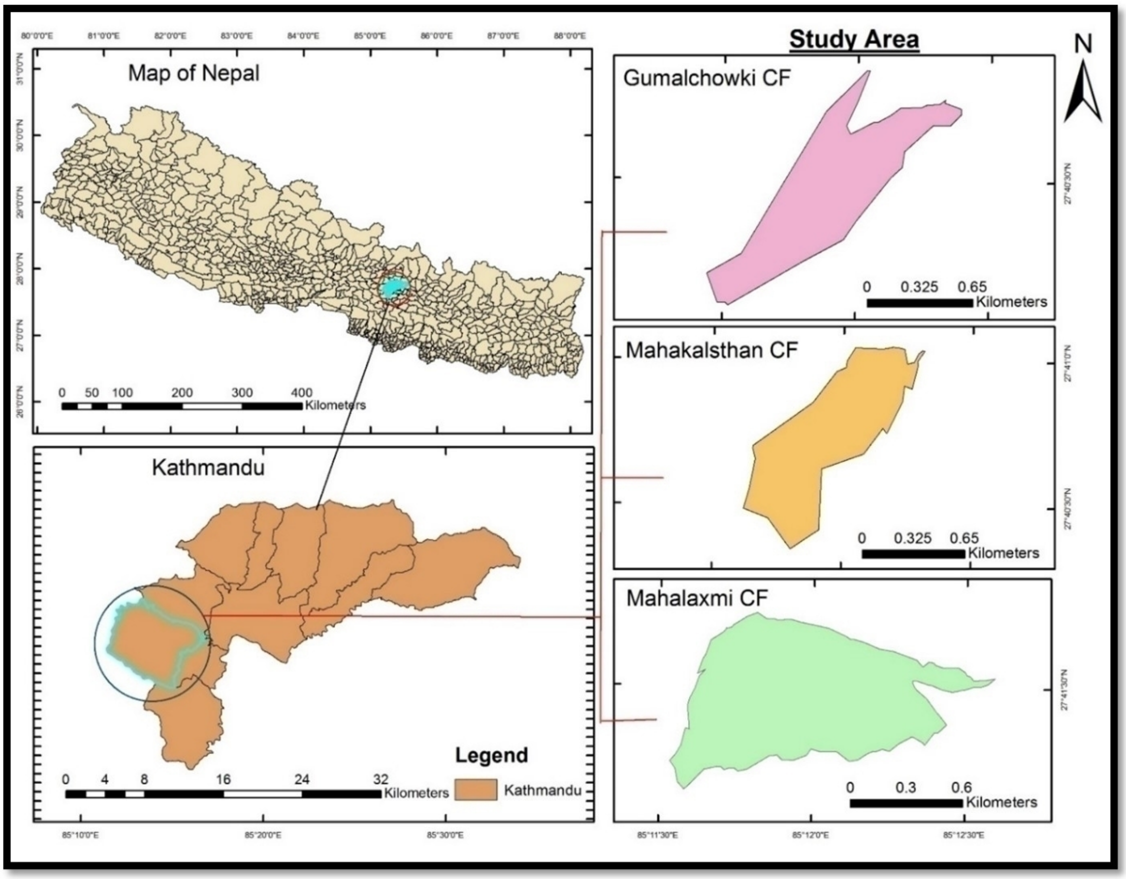


Figure 1 - Map of study area

SAMPLING DESIGN

Simple random sampling with 3.3%, 3.6% and 2.5% sampling intensity was applied to Gumalchowki CF, Mahakalsthan CF and Mahalaxmi CF respectively.

FOREST DATA COLLECTION

Both primary and secondary data collection was carried out in the research. Direct field observation, inventory and key informant interview (KII) were included under primary data collection while, internet surfing, books, reports, journals and community forest operational plan were included under secondary data in order to meet the research objectives. Total 135 sample plots were established to collect the data. The nested plot method suggested by Ravindranath & Ostwald, (2008) was used in the sampling design to minimize edge effects, which usually occur in rectangular or square plots. A circular plot of 500 m² with 12.61 m radius was set up to measure the diameter at breast height (DBH) the trees and poles (>10cm), while 100 m2 with 5.64 m radius was established for saplings (

The diameter at breast height (DBH at 1.3m height) and height of individual trees and pole greater than or equal to 5cm were measured and recorded. Leaf, litter, herbs, and grass samples were taken. For this, destructive sampling was used, with the fresh weight being obtained and the dried weight being recorded in the lab.

DATA ANALYSIS

The total above ground biomass was calculated by summing carbon in above ground tree biomass, carbon in above ground sapling biomass and carbon in leaf litter, herbs and grass biomass.

ABOVE GROUND BIOMASS ESTIMATION

The total above-ground trees/poles biomass was calculated using the equation (model) developed by (Chave et al., 2005).

$$AGTB=0.0509 \times \rho.D.D.H$$

Where,

AGTB = above-ground tree biomass (kg),

ρ = wood specific gravity (gm/cm³), D = tree diameter at breast height (cm) and H = tree height (m).

The tree biomass, carbon stock in kg/m² was calculated by multiplying the total of all the individual weights in kg of a sampling plot by the area of the sample plot (m²). The unitary method was used to convert the value to t/ha.

BIOMASS OF LEAF LITTER, HERBS AND GRASS

In the case of herbs, grass, and litter and small sized plants (DBH

$$Biomass\left(\frac{t}{ha}\right) = \left(\frac{W\,field}{A}\right) \times \left(\frac{W\,sample, dry}{Wsample, wet}\right) \times \frac{1}{10000}$$

Where,

W field = weight of the fresh field sample of leaf litter, herbs, and grasses, which was sampled destructively within the given area in (g)

A = size of the area in which leaf litter, herbs, and the grass was collected (ha);

W sample, dry = weight of the oven-dry sub-sample of leaf litter, herbs and grasses that was taken to determine moisture content (g); (Approximately 40% of the fresh weight)

And, W sample, wet = weight of the fresh sub-sample of leaf litter, herbs, and grasses that was taken to determine moisture content (g)

CALCULATION OF CARBON STOCK

Biomass value was converted into carbon stock while biomass was multiplied by the default carbon fraction of 0.47 (IPCC, 2006; McGroddy et al., 2004).

$$\text{Carbon stock} = AGTB \times 0.47$$

Where,

AGTB= Above ground total biomass

The total carbon in Above Ground Biomass will be calculated by the formula:

$$C(TAGB)=C(AGTB)+C(AGSB)+C(LHGB)$$

Where,

C (TAGB) = Total carbon in above ground biomass (t/ha)

C (AGTB) = Carbon in above ground tree biomass (t/ha)

C (AGSB) = Carbon in above ground sapling biomass (t/ha)

C (LHGB) = Carbon in leaf litter, herbs and grass biomass (t/ha)

CALCULATION OF DIFFERENT VEGETATION INDICES (VIs)

Landsat 8 (OLI) was downloaded from United States Geological Survey (USGS: https://www.usgs.gov/). The red band and infrared band reflections can be used to monitor the intensity and density of green vegetation growth.

Green vegetation reflects more energy in the near infrared band that in the visible range. It observes red band more for the photosynthesis process. Therefore, the vegetation indices comprise of the bands were used to correlate the field measured carbon stock with the help of GPS coordinates.

The coordinates of the ground based carbon measurement was used to correlate the reflectance value of the pixel of imageries where ground data were collected.

S.N.	Vegetation Index	Formula	Range	Introduced by:
1.	Difference Vegetation Index (DVI)	$DVI = NIR - RED$	∞ (Infinite)	Lillesand et al., (2015)
2.	Infrared Percentage Vegetation Index (IPVI)	$IPVI = \frac{NIR}{NIR + RED}$	0 to +1	(Karnell et al., 2007)
3.	Normalized Difference Vegetation Index (NDVI)	$NDVI = \frac{NIR - RED}{NIR + RED}$	-1 to +1	Tucker, (1979)

Table 1 - Table showing information about vegetation indices

STATISTICAL ANALYSIS

The Kolmogorov-Smirnov and Shapiro –Wilk was performed to check the normality of data. The collected data set showed normal thus further correlation was performed. Afterward, Pearson's correlation analysis was used to explore the correlation between carbon stock and vegetation indices. ANOVA and t-test were performed to check the equation, intercept and constant were significant at 95% confidence level.

Finally, Root Mean Square Error (RMSE), RMSE%, Bias, Bias%, Root Mean Squared Error Ratio (RSR) were calculated to examine the performance of the equation comparing the predicted value and actual value calculated additional field data set.

RESULT AND DISCUSSION

AVERAGE HEIGHT AND DBH CLASS OF STEMS IN COMMUNITY FORESTS

The average height and diameter class was varying in the community forest. The highest dimeter class was recorded DBH>50 cm and the average height in this class was 19.36, 17.74 and 16.67 whereas the average height of stem in lowest DBH class (0-10cm) was 6.52, 5.99 and 6.54 m m in Gumalchowki, Mahakalsthan and Mahalaxmi CF respectively (Table 2).

Diameter class (cm)	Average height (m)			Remarks
	Gumalchowki CF	Mahakalsthan CF	Mahalaxmi CF	
0-10	6.52	5.99	6.54	
10.1-20	9.48	9.43	10.07	
20.1-30	10.86	10.32	10.54	
30.1-40	14.43	13.09	12.93	
40.1-50	15.98	14.53	15.22	
> 50	19.36	17.74	16.67	

Table 2 - Carbon stock (ton/ha) according to DBH in CFs

DESCRIPTIVE ANALYSIS OF CARBON STOCK (TON/HA) AND DENSITY (N/HA) OF DIFFERENT CFS

The descriptive statistics was of carbon stock in the community forest was varying according to DBH class. The estimated carbon stock was the highest in DBH > 50 cm with 13.47±1.34, 12.25±1.00 and 10.51±0.80 ton/ha in Gumalchowki CF, Mahalxmi CF and Mahakalsthan CF respectively. However, the lowest record of carbon stock was found in DBH

Community forests	Description	Gumalchowki CF			Mahakalsthan CF			Mahalaxmi CF		
Diameter class (cm)		Mean±SE	SD	Range	Mean±SE	SD	Range	Mean±SE	SD	Range
0-10	Carbon	218.18±20.42	95.8	100-400	190±34.72	155.26	100-700	214.29±26.08	119.52	100-600
10.1-20	Carbon	421.43±38.18	247.46	100-900	443.59±34.42	214.96	100-1000	342.5±40.81	258.09	100-1100
20.1-30	Carbon	323.81±31.38	203.4	100-1000	402.33±28.53	187.07	100-800	358.54±26.36	168.78	100-900
40.1-50	Carbon	24±2.89	11.21	20-60	40±6.41	23.09	20-80	30.37±3.6	18.7	20-100
> 50	Carbon	27.5±5.26	14.88	20-60	31.67±3.86	13.37	20-60	30.83±3.4	16.66	20-80

Table 3 - Descriptive analysis of Carbon stock (ton/ha) of CFs

COEFFICIENT OF VARIATION (CV) OF CARBON STOCK SHOWING DIAMETER CLASS IN COMMUNITY FORESTS

Coefficient of variance is the ratio of standard deviation to the mean. The higher the coefficient of variation, the greater is the level of relative variability and vice versa.

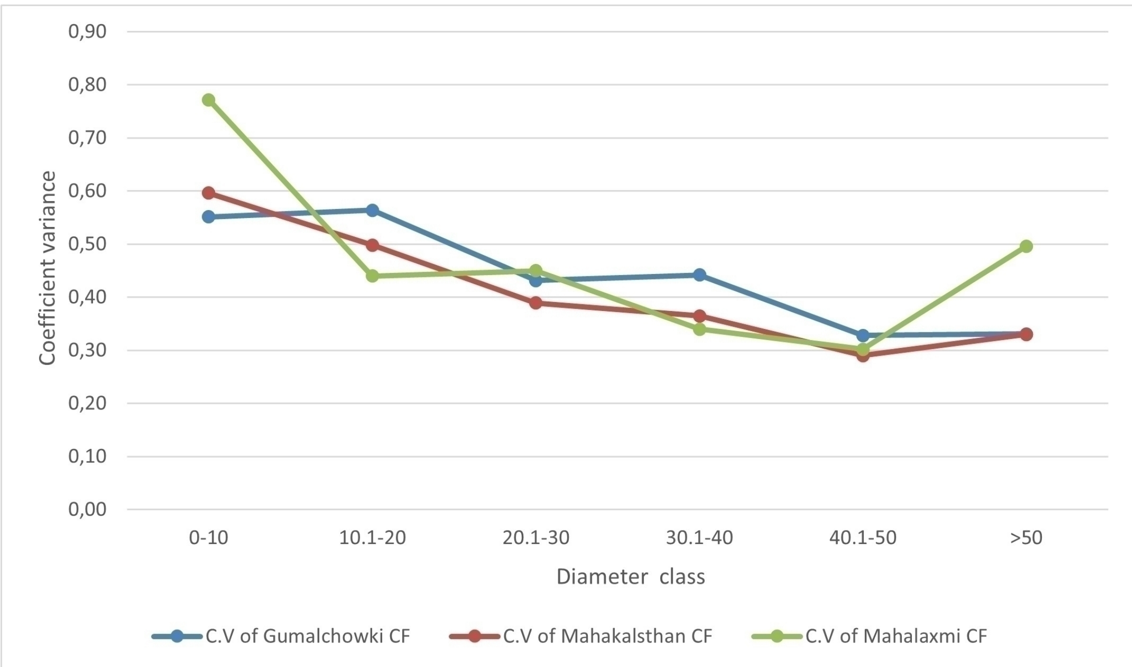
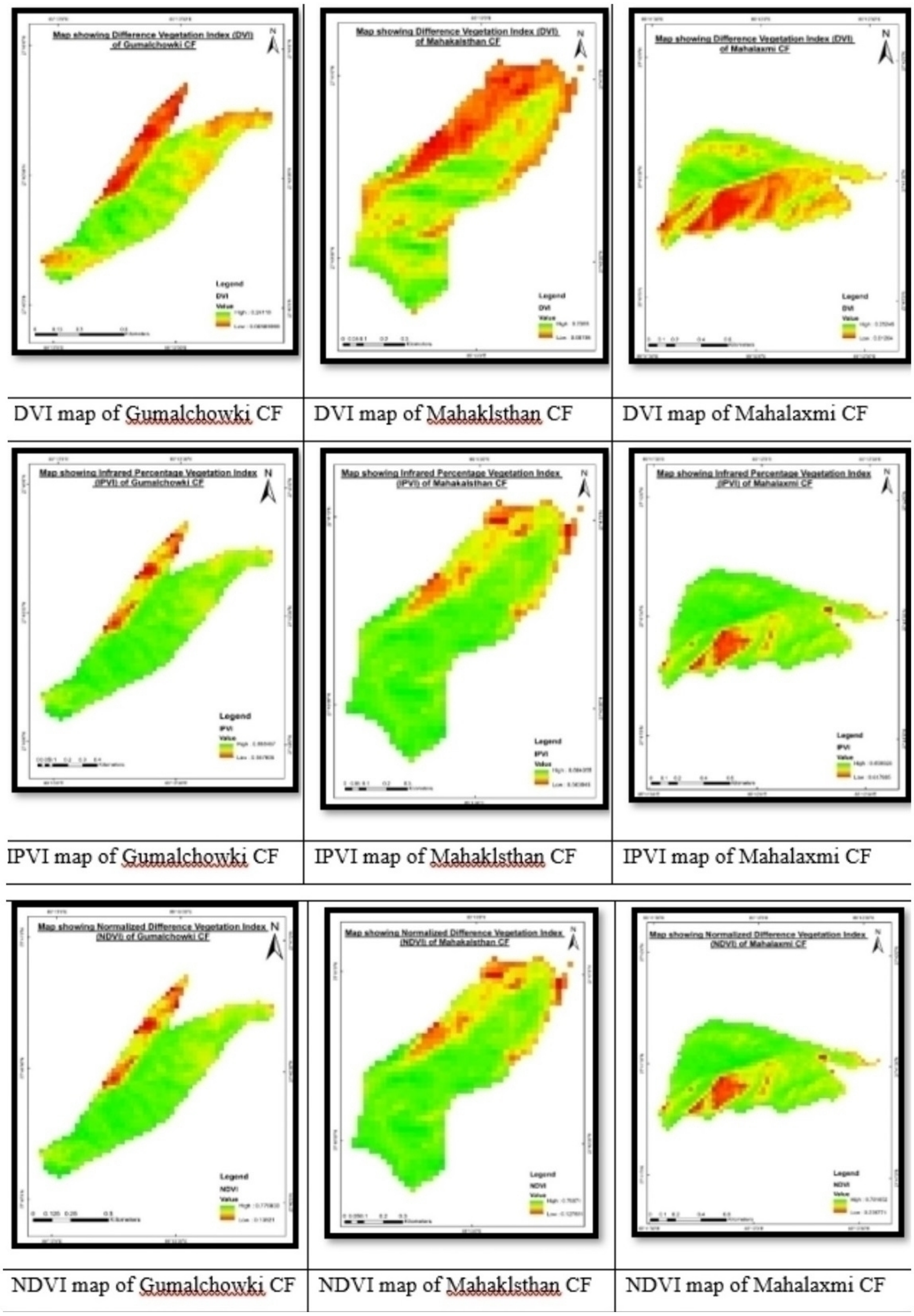


Figure 2 - Coefficient of variance and diameter class of community forests

Figure 2, illustrates that, the coefficient of variance of DBH class 40.1-50 cm of all community forests was the lowest with 0.30 to 0.33 while this was the highest of DBH> 50 cm and DBH50 cm.

MAP OF SHOWING DVI, IPVI AND NDVI OF COMMUNITY FOREST

Total nine maps were produced to show the different indices in community forests. The reflectance value was estimated to correlate with carbon stock in the community forest using GPS coordinates.



DVI map of Gumalchowki CF	DVI map of Mahaklsthan CF	DVI map of Mahalaxmi CF
IPVI map of Gumalchowki CF	IPVI map of Mahaklsthan CF	IPVI map of Mahalaxmi CF
NDVI map of Gumalchowki CF	NDVI map of Mahaklsthan CF	NDVI map of Mahalaxmi CF

Figure 3 - Map of different indexed of community forests.

CORRELATION BETWEEN DIFFERENT VEGETATION INDEX AND CARBON STOCK

NDVI VS CARBON STOCK IN COMMUNITY FORESTS

The scatter plots were drawn to show the relationship between carbon stock and reflectance value of the derived indices. The strong and positive correlation was found between the value of NDVU and carbon in the community forest. The R^2 of relation between carbon stock and NDVI was 0.51, 0.54 and 0.58 in Gumalchowki, Mahakalsthan and Mahalaxmi CF respectively (figure 4 to 6). The ANOVA and t-test was also performed significant since the P-value was less than 0.05 in all CFs. Similarly, the relationship between DVI and carbon stock (ton/ha) was also positive in the community forests. The R^2 values of relation between carbon stock and DVI were 0.49, 0.46 and 0.46 in Gumalchowki, Mahakalsthan and Mahalaxmi CF respectively (figure 7 to 9). Applied ANOVA and t-test showed the significant correlation between these two variables since $P < 0.05$ in all CFs. Moreover, correlation between reflect the carbon stock and IPVI values was also positive in the community forests. The value of R2 of relation between carbon stock and IPVI was 0.44, 0.41 and 0.435 in Gumalchowki, Mahakalsthan and Mahalaxmi CF respectively. The equation, intercept and constant of equation was examined using ANOVA and t- test which showed significant since P

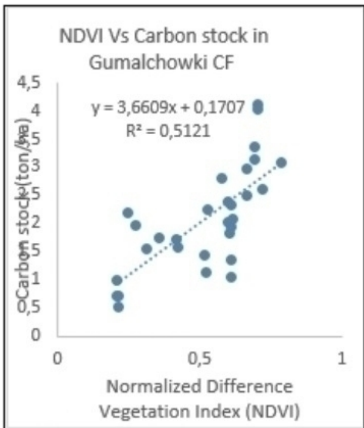


Figure 4: NDVI Vs carbon stock in Gumalchowki CF

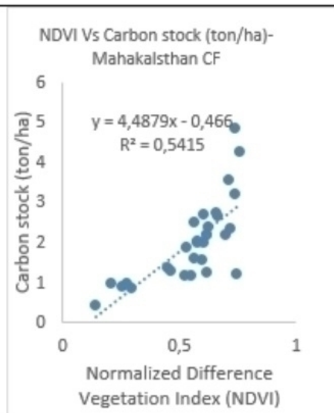


Figure 5: NDVI Vs carbon stock in Mahakalsthan CF

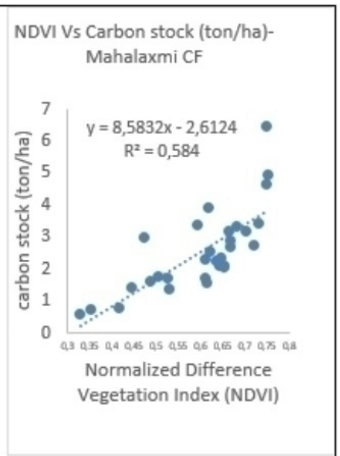


Figure 6: NDVI Vs carbon stock in Mahalaxmi CF

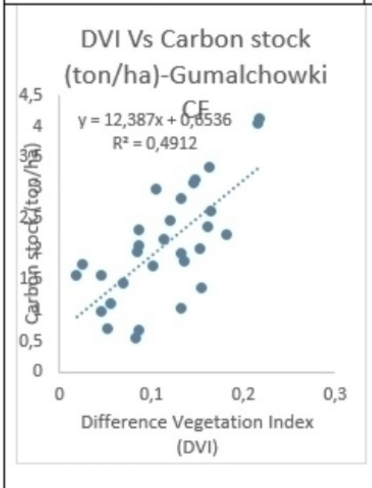


Figure 7: DVI Vs carbon stock (ton/ha) in Gumalchowki CF

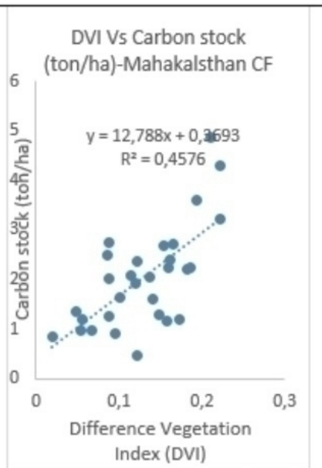


Figure 8: DVI Vs carbon stock (ton/ha) in Mahakalsthan CF

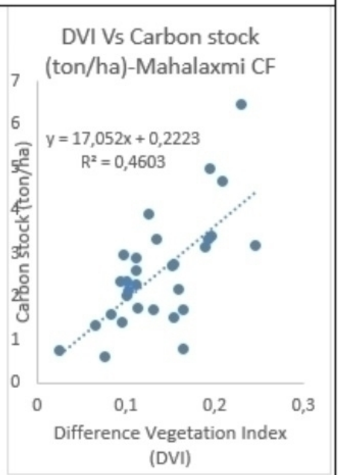


Figure 9: DVI Vs carbon stock (ton/ha) in Mahalaxmi CF

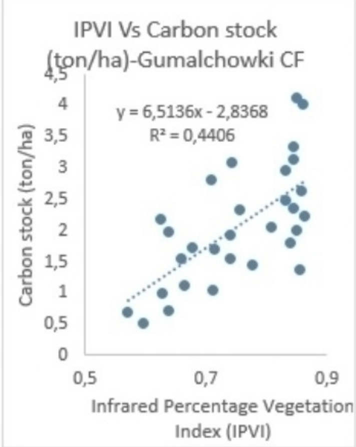


Figure 10: IPVI Vs carbon stock (ton/ha) in Gumalchowki CF

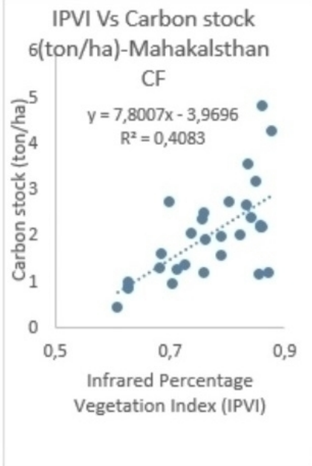


Figure 11: IPVI Vs carbon stock (ton/ha) in Mahakalsthan CF

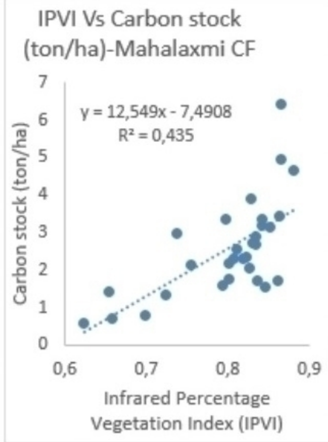


Figure 12: IPVI Vs carbon stock (ton/ha) in Mahalaxmi CF

ERROR ANALYSIS BETWEEN INDICES AND CARBON STOCK:

The equation of carbon stock and different vegetation indexes was evaluated using RMSE, RMSE%, RSR, Bias and Bias%. In fact lower value of RMSE, RMSE%, RSR, Bias and Bias % indicated high performance of the equation. For example the low value of RMSE was 1.36 which indicated the equation developed showing relation between carbon stock and NDVI in Mahakalsthan CF could performed good enough to evaluate the carbon stock. Similar result was found in Gumalchowki CF, the bias percentage was only 0.07% and vice versa in Mahalaxmi CF with RSR only 0.29 (Table 4).

S.N.	Details	Gumalchowki CF	Mahakalsthan CF	Mahalaxmi CF
Error analysis of predicted and observed value of NDVI in community forests				
1.	RMSE	1.41	1.36	1.91
2.	RMSE%	0.65%	0.60%	0.50%
3.	RSR	0.95	1.22	0.29
4.	Bias	0.14	-0.37	-1.09
5.	Bias%	0.07%	-0.16%	-0.28%
Error analysis of predicted and observed values of DVI of community forests				
1.	RMSE	1.46	1.53	2.23
2.	RMSE%	0.67%	0.68%	0.58%
3.	RSR	0.99	1.38	1.28
4.	Bias	-0.18	-0.66	-1.38
5.	Bias%	-0.08%	-0.29%	-0.36%
Error analysis of predicted and observed values of IPVI of community forests				
1.	RMSE	1.41	1.21	1.82
2.	RMSE%	0.65%	0.53%	0.47%
3.	RSR	0.95	0.48	1.05
4.	Bias	0.16	-0.34	-0.91
5.	Bias%	0.07%	-0.31%	-0.24%

Table 4 - Errors in predicted and observed values of vegetation indices of community forests

CAUSES OF DEFORESTATION AND FOREST DEGRADATION IN COMMUNITY FORESTS

The factors affecting the carbon stock in community forest was performed using principal component analysis (PCA). Here, landslide, expansion of transmission line and soil erosion were highly correlated causing deforestation but weeds, fire, disease and poles collection from the forest were highly correlated with each other which causing the degradation in Gumalchowki CF.

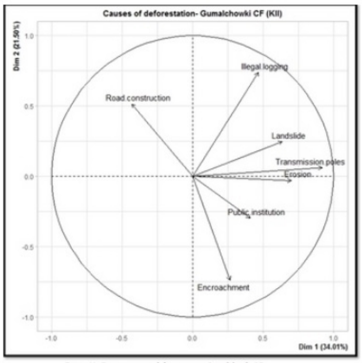


Figure 13: Factors causing deforestation in Gumalchowki CF

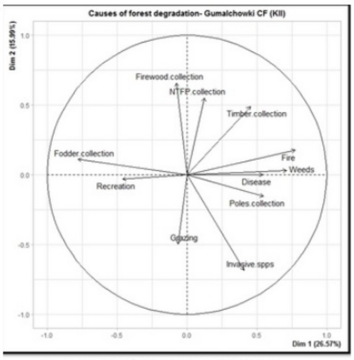


Figure 14: Factors causing forest degradation causing: Gumalchowki CF

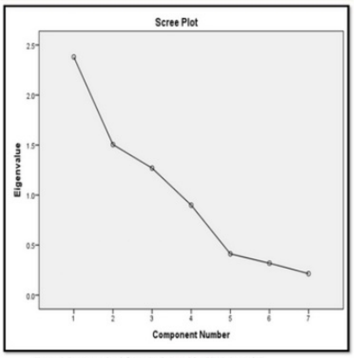


Figure 15: Factors causing deforestation in Gumalchowki CF (Scree plot)

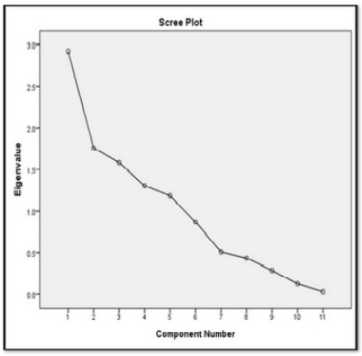


Figure 16: Factors causing forest degradation in Gumalchowki CF (Scree plot)

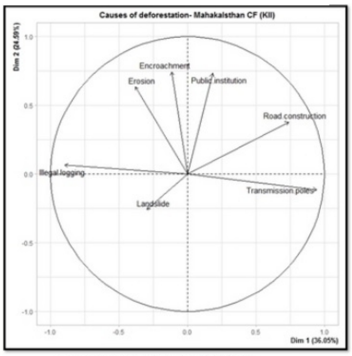


Figure 17: Factors causing deforestation in Mahakalsthan CF

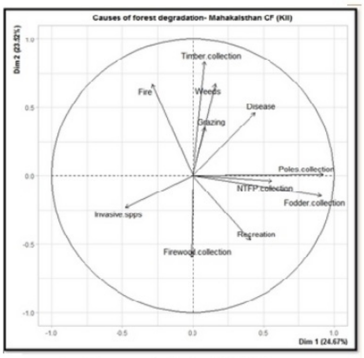


Figure 18: Factors causing forest degradation Mahakalsthan CF

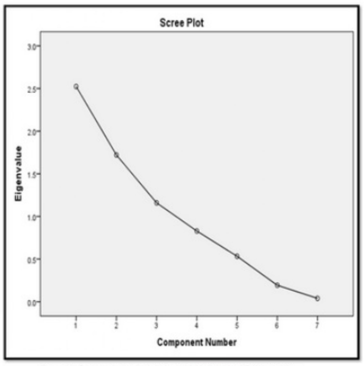


Figure 19: Factors causing deforestation in Mahakalsthan CF (Scree plot)

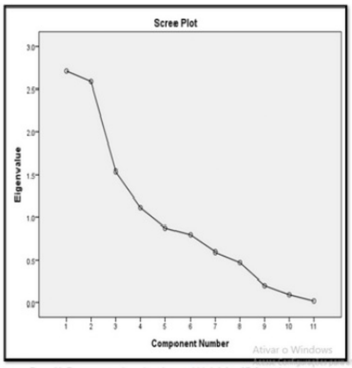


Figure 20: Factors causing forest degradation in Mahakalsthan CF (Scree plot)

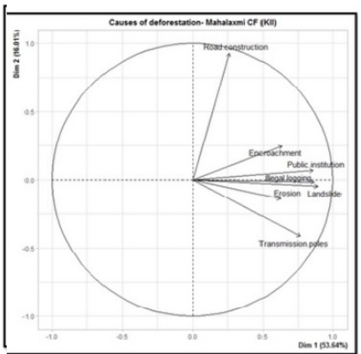


Figure 21: Factors causing deforestation in Mahalaxmi CF

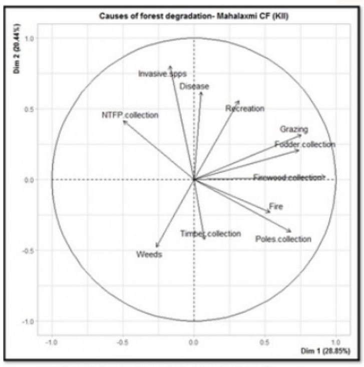


Figure 22: Factors causing forest degradation Mahalaxmi CF

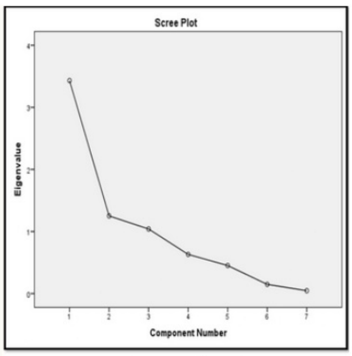


Figure 23: Factors causing deforestation in Mahlaxmi CF (Scree plot)

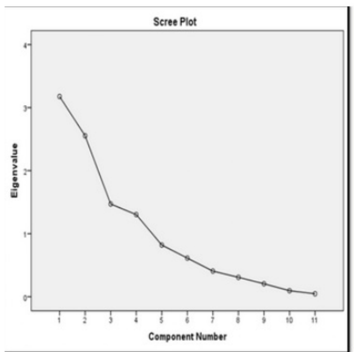


Figure 24: Factors causing forest degradation in Mahalaxmi CF (Scree plot)

The scree plot showed that, there was three factors having eigenvalue greater than 1, showed greater variance factors causing the deforestation. Likewise, forest degradation was caused by road construction, erosion, illegal logging and transmission line expansion. Similar types of result were recorded in Mahakalsthan and Mahalaxmi community forests (figure 13 to 24).

DISCUSSION

The amount of carbon stock was found to be highest in Mahalaxmi CF with 30.42 ton/ha, followed by Mahakalsthan CF with 22.62 ton/ha. Likewise, Gumalchowki CF has comparatively lowest amount of carbon stocked with 21.55 ton/ha. Mahalaxmi CF has comparatively higher diameter trees, moist content and leaf litter than in Mahakalsthan and Gumalchowki CF. The quantity of carbon stock varies according to the time, vegetation type, geographic location, and management technique used (K. C., 2019). It was recorded that higher the diameter class, higher will be the amount of carbon stock. Also, the rates of carbon fixation vary with forest age, species and site (Grierson et al., 1992).

The carbon stock was the highest in Pinus wallichiana in Gumalchowki and Mahalaxmi CF whereas, it was the highest in Pinus roxburghii in Mahakalsthan CF. Comparably, Rhodedendron arboretum had stocked carbon at the least amount in all CFs. All the community forests are facing at the northern aspect, due to which the amount of carbon stock by Pinus spp was higher. The research conducted in two CFs from Myagdi and a CF from Sindhupalchowk district had shown that the above and below ground carbon stock was largest in the north aspect, while it was lowest in the west aspect in case of Pinus roxburghii (Mandal et al., 2017). The study done in plantation forest of Kathmandu valley had also showed that the pine has larger biomass, and carbon stock, the reliable reason may be having large diameter (Sharma et al., 2020). The study done in Muree hills of Pakistan, revealed that the average stem density ranged from 636±93 (trees ha^{-1}) in the young stand to 147±56.7 (trees ha^{-1}) in the overmature stand. The young stand had a statistically higher stem density, while the overmature plant had a lower stem density. The basal area in young, mature, and over mature stands was 15.51±1.6 (m^2 ha^{-1}), 35.57±18.0 (m^2 ha^{-1}), and 45.91±15.1 (m^2 ha^{-1}), respectively (Amir et al., 2018). The result of this research are differed from published papers by different authors, the reliable reason is the diverse geography and forest condition.

The study shows the significant relationship of carbon stock and different indices (DVI, IPVI, NDVI). The result of this research study was similar to Shrestha et al., (2013). They found the carbon stock value of 91.04tC/ha in Simsungure CF, 87.42tC/ha Mahankal CF, 36.41tC/ha Mathani CF, 411.32tC/ha Sitakunda CF, 21.83tC/ha Barkhe and CF, 56.6tC/ha Chyansi CF. Their findings revealed that there were strong correlations between carbon stock and reflectance value of remote sensing data. Similar result was shown by the study done in Savannakhet Province, Lao PDR between the AGB and Landsat (Vicharnakorn et al., 2014).

There are different methods to validate the data, among them from the residual plots the equation representing different indices and the carbon stock was found to be more precise moreover, the values of RMSE, RMSE%, RSR, bias and percentage bias were less. Several authors conduct and support this concept of validating the data. Mandal et al., (2020); Volkanovski et al., (2009) and many authors perform this method for the validation of the data.

Several factors are affecting the carbon in the community forest. The over extraction of timber, increasing weeds, over and uncontrolled grazing, diseases and pest, fodder collection were the major cause of low carbon stock. This finding was matching with study done by Megevand & Mosnier, (2013), Mfon et al., (2014), Kumar, R., & Saikia (2020). The reason may be having similar types social and economic complexity in the study sites.

CONCLUSION

The community forest enhances the biomass and carbon. Carbon stock monitoring might be a quick and cost-effective technique to estimate carbon dioxide emissions while also contributing to forest biodiversity. Mahalaxmi CF has the most carbon stock followed by Mahakalsthan CF with and Gumalchowki CF. Pinus spss. were recorded to stock more amount of carbon in all three forests.

Through different calculations, it clearly indicates that the consistency won't be seen over these forests in near future as there is no uniformity in carbon stock by the regenerating seedlings, saplings and poles.

The analysis found significant positive connection between carbon stock and three distinct indices (i.e. DVI, IPVI, NDVI). The equation expressing different indices and the carbon stock are more exact, according to the residual plots of all community forests and the lower value of RSR, RMSE, RMSE%, bias, bias% shows high accuracy.

Fire, landslide, soil erosion, transmission poles, recreation, poles collection, firewood collection, diseases, weeds, encroachment are major causes that had been negatively affecting on the amount of carbon being stocked in all three community forests.

This study will be useful in establishing the baseline data on carbon stock in Kathmandu valley. Similar research based on different forest types, climatic zones, soil types, altitude and aspect should be done to monitor carbon stock and findings more general.

REFERENCES

Amir, M., Liu, X., Ahmad, A., Saeed, S., Mannan, A., & Muneer, M. A. (2018). Patterns of Biomass and Carbon Allocation across Chronosequence of Chir Pine (Pinus roxburghii) Forest in Pakistan: Inventory-Based Estimate. Advances in Meteorology, 2018, 1–8. https://doi.org/10.1155/2018/3095891

Asner, G. P., Powell, G. V. N., Mascaro, J., Knapp, D. E., Clark, J. K., Jacobson, J., Kennedy-Bowdoin, T., Balaji, A., Paez-Acosta, G., Victoria, E., Secada, L., Valqui, M., & Hughes, R. F. (2010). High-resolution forest carbon stocks and emissions in the Amazon. Proceedings of the National Academy of Sciences, 107(38), 16738–16742. https://doi.org/10.1073/pnas.1004875107

Bhandari, M. (2012). International Centre for Integrated Mountain Development. In G. Ritzer (Ed.), The Wiley-Blackwell Encyclopedia of Globalization (p. wbeog308). John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470670590.wbeog308

Boyd, D. S., Foody, G. M., & Curran, P. J. (Centre for E. and E. S. R. (1999). The relationship between the biomass of Cameroonian tropical forests and radiation reflected in middle infrared wavelengths (3.0-5.0 micro m). International Journal of Remote Sensing (United Kingdom). https://agris.fao.org/agris-search/search.do?recordID=GB1999005197

Cao, J., Wang, X., Tian, Y., Wen, Z., & Zha, T. (2012). Pattern of carbon allocation across three different stages of stand development of a Chinese pine (Pinus tabulaeformis) forest. Ecological Research, 27(5), 883–892. https://doi.org/10.1007/s11284-012-0965-1

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.-P., Nelson, B. W., Ogawa, H., Puig, H., Riéra, B., & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145(1), 87–99. https://doi.org/10.1007/s00442-005-0100-x

Cui, L., Jiao, Z., Dong, Y., Sun, M., Zhang, X., Yin, S., ... & Xie, R. (2019). Estimating forest canopy height using MODIS BRDF data emphasizing typical-angle reflectances. Remote Sensing, 11(19), 2239.

Foody, G. M., Boyd, D. S., & Cutler, M. E. J. (2003). Predictive relations of tropical forest biomass from Landsat TM data and their transferability between regions. Remote Sensing of Environment, 85(4), 463–474. https://doi.org/10.1016/S0034-4257(03)00039-7

Grierson, P., Adams, M., & Attiwill, P. (1992). Estimates of Carbon Storage in the Aboveground Biomass of Victorias Forests. Australian Journal of Botany, 40(5), 631. https://doi.org/10.1071/BT9920631

Gunawardena, A., Iftekhar, S., & Fogarty, J. (2020). Quantifying intangible benefits of water sensitive urban systems and practices: an overview of non-market valuation studies. Australasian Journal of Water Resources, 24(1), 46-59.

Hunt, C. A. G. (2009). Carbon Sinks and Climate Change: Forests in the Fight Against Global Warming. Edward Elgar Publishing.

Ingram, J. C., Dawson, T. P., & Whittaker, R. J. (2005). Mapping tropical forest structure in southeastern Madagascar using remote sensing and artificial neural networks. Remote Sensing of Environment, 94(4), 491–507. https://doi.org/10.1016/j.rse.2004.12.001

IPCC. (2006). Forestland. In: IPCC Guidelines for National Greenhouse Gas Inventories .eds Eggleston HS., Buendia L., Miwa K., Ngara T. and Tanabe K), pp. 4.1–4.83. IPCC, Japan.

Jordan, C. F. (1969). Derivation of Leaf-Area Index from Quality of Light on the Forest Floor. Ecology, 50(4), 663–666. https://doi.org/10.2307/1936256

K. C., A. (2019). Forest as a Sink of Carbon in Global and Nepalese Context. In M. K. Jhariya, A. Banerjee, R. S. Meena, & D. K. Yadav (Eds.), Sustainable Agriculture, Forest and Environmental Management (pp. 223–249). Springer Singapore. https://doi.org/10.1007/978-981-13-6830-1_7

Karnell, M. P., Melton, S. D., Childes, J. M., Coleman, T. C., Dailey, S. A., & Hoffman, H. T. (2007). Reliability of Clinician-Based (GRBAS and CAPE-V) and Patient-Based (V-RQOL and IPVI) Documentation of Voice Disorders. Journal of Voice, 21(5), 576–590. https://doi.org/10.1016/j.jvoice.2006.05.001

Kumar, R., & Saikia, P. (2020). Forest resources of Jharkhand, Eastern India: socio-economic and bio-ecological perspectives. In Socio-economic and Eco-biological Dimensions in Resource use and Conservation (pp. 61-101). Springer, Cham.

Lillesand, T., Kiefer, R. W., & Chipman, J. (2015). Remote Sensing and Image Interpretation. John Wiley & Sons.

Lu, D., Mausel, P., Brondızio, E., & Moran, E. (2004). Relationships between forest stand parameters and Landsat TM spectral responses in the Brazilian Amazon Basin. Forest Ecology and Management, 198(1–3), 149–167.

Mandal, R. A., Jha, P. K., Dutta, I. C., Thapa, U., & Karmacharya, S. B. (2016). Carbon Sequestration in Tropical and Subtropical Plant Species in Collaborative and Community Forests of Nepal. Advances in Ecology, 2016, 1–7. https://doi.org/10.1155/2016/1529703

Mandal, R. A., Khadka, G. B., Shrestha, M., Sah, P., & Lamichhane, A. (2020). Modeling the diameter at breast height (DBH) with height and volume of Shorea robusta using destructive method: A study from Banke District, Nepal. 15.

Mandal, R., Aryal, K., & Gupta, J. (2017). Effects of Hilly Aspects on Carbon Stock of Pinus roxburghii Plantations in Kaleri, Salyan Salleri and Barahpakho Community Forests. Journal of Climate Change Research, 3, 816–824.

Maynard, C. L., Lawrence, R. L., Nielsen, G. A., & Decker, G. (2007). Modeling vegetation amount using bandwise regression and ecological site descriptions as an alternative to vegetation indices. GIScience & Remote Sensing, 44(1), 68–81.

McGroddy, M. E., Daufresne, T., & Hedin, L. O. (2004). SCALING OF C:N:P STOICHIOMETRY IN FORESTS WORLDWIDE: IMPLICATIONS OF TERRESTRIAL REDFIELD-TYPE RATIOS. Ecology, 85(9), 2390–2401. https://doi.org/10.1890/03-0351

Megevand, C., & Mosnier, A. (2013). Deforestation trends in the Congo Basin: reconciling economic growth and forest protection. World Bank Publications.

Mfon, P., Akintoye, O. A., Mfon, G., Olorundami, T., Ukata, S. U., & Akintoye, T. A. (2014). Challenges of deforestation in Nigeria and the Millennium Development Goals. International Journal of Environment and Bioenergy, 9(2), 76-94.

Näsi, R., Honkavaara, E., Lyytikäinen-Saarenmaa, P., Blomqvist, M., Litkey, P., Hakala, T., & Holopainen, M. (2015). Using UAV-based photogrammetry and hyperspectral imaging for mapping bark beetle damage at tree-level. Remote Sensing, 7(11), 15467-15493.

Palmer, C. (2011). Property rights and liability for deforestation under REDD+: Implications for permanence' in policy design. Ecological economics, 70(4), 571-576.

Ravindranath, N. H., & Ostwald, M. (Eds.). (2008). Methods for Estimating Above-Ground Biomass. In Carbon Inventory Methods Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects (pp. 113–147). Springer Netherlands. https://doi.org/10.1007/978-1-4020-6547-7_10

Schlerf, M., Atzberger, C., & Hill, J. (2005). Remote sensing of forest biophysical variables using HyMap imaging spectrometer data. Remote Sensing of Environment, 95(2), 177–194.

Sharma, I., & Kakchapati, S. (2018). Linear Regression Model to Identify the Factors Associated with Carbon Stock in Chure Forest of Nepal. Scientifica, 2018, 1–8. https://doi.org/10.1155/2018/1383482

Sharma, K. P., Bhatta, S. P., Khatri, G. B., Pajiyar, A., & Joshi, D. K. (2020). Estimation of Carbon Stock in the Chir Pine (Pinus roxburghii Sarg.) Plantation Forest of Kathmandu Valley, Central Nepal. Journal of Forest and Environmental Science, 36(1), 37–46. https://doi.org/10.7747/JFES.2020.36.1.37

Shrestha, S., Karky, B. S., Gurung, A., Bista, R., & Vetaas, O. R. (2013). Assessment of Carbon Balance in Community Forests in Dolakha, Nepal. Small-Scale Forestry, 12(4), 507–517. https://doi.org/10.1007/s11842-012-9226-y

Smith, B., Knorr, W., Widlowski, J. L., Pinty, B., & Gobron, N. (2008). Combining remote sensing data with process modelling to monitor boreal conifer forest carbon balances. Forest Ecology and Management, 255(12), 3985-3994.

Soenen, S. A., Peddle, D. R., Hall, R. J., Coburn, C. A., & Hall, F. G. (2010). Estimating aboveground forest biomass from canopy reflectance model inversion in mountainous terrain. Remote Sensing of Environment, 114(7), 1325-1337.

Steininger, M. K. (2000). Satellite estimation of tropical secondary forest above-ground biomass: Data from Brazil and Bolivia. International Journal of Remote Sensing, 21(6–7), 1139–1157.

Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment, 8(2), 127–150. https://doi.org/10.1016/0034-4257(79)90013-0

Vicharnakorn, P., Shrestha, R., Nagai, M., Salam, A., & Kiratiprayoon, S. (2014). Carbon Stock Assessment Using Remote Sensing and Forest Inventory Data in Savannakhet, Lao PDR. Remote Sensing, 6(6), 5452–5479. https://doi.org/10.3390/rs6065452

Volkanovski, A., Čepin, M., & Mavko, B. (2009). Application of the fault tree analysis for assessment of power system reliability. Reliability Engineering & System Safety, 94(6), 1116–1127. https://doi.org/10.1016/j.ress.2009.01.004

Zheng, D., Rademacher, J., Chen, J., Crow, T., Bresee, M., Le Moine, J., & Ryu, S.-R. (2004). Estimating aboveground biomass using Landsat 7 ETM+ data across a managed landscape in northern Wisconsin, USA. Remote Sensing of Environment, 93(3), 402–411.

Zhong, X., Li, J., Li, X., Ye, Y., Liu, S., Hallett, P. D., Ogden, M. R., & Naveed, M. (2017). Physical protection by soil aggregates stabilizes soil organic carbon under simulated N deposition in a subtropical forest of China. Geoderma, 285, 323–332. https://doi.org/10.1016/j.geoderma.2016.09.026

Zianis, D., Muukkonen, P., Mäkipää, R., & Mencuccini, M. (2005). Biomass and stem volume equations for tree species in Europe. FI.