








An Approach for Fraction of Vegetation Cover Estimation in Forest Above-Ground Biomass Assessment Using Sentinel-2 Images

Praveen Kumar¹ , Akhouri P. Krishna¹ , Thorkild M. Rasmussen² ,
and Mahendra K. Pal²  

¹ Department of Remote Sensing, BIT Mesra, Ranchi 835 215, Jharkhand, India

² Division of Geosciences and Environmental Engineering, Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, 971 87 Luleå, Norrbotten County, Sweden

mahendra.pal@ltu.se

Abstract. Forests are one of the most important components to balance and regulate the terrestrial ecosystem on the Earth in protecting the environment. Accurate forest above-ground biomass (AGB) assessment is vital for sustainable forest management to recognize climate change and deforestation for mitigation processes.

In this study, Sentinel 2 remote sensing image has been used to calculate the fraction of vegetation cover (FVC) in order to accurately estimate the forest above-ground biomass of Tundi reserved forest in the Dhanbad district located in the Jharkhand state, India. The FVC is calculated in four steps: first, vegetation index image generation; second, vegetation index image rescaled between 0 to 1; third, the ratio of vegetated and non-vegetated areas was calculated with respect to the total image area, and finally, FVC image is generated.

In this paper, three vegetation indices have been calculated from the Sentinel 2 image, namely: normalized difference vegetation index (NDVI), normalized difference index 45 (NDI45), and inverted red-edge chlorophyll index (IRECI). Then, the FVC images were generated from the above vegetation indices individually. The ground FVC values were estimated from 22 different locations from the study area. Finally, the image based FVC estimates were compared with the ground estimated FVC. The results show that the IRECI based FVC provided the best approximation to the ground FVC among the different vegetation indices tested.

Keywords: Vegetation indices · Fraction of vegetation cover · Forest above ground biomass · Sentinel 2 images · Optical remote sensing

1 Introduction

Forest are one among the most dominant factors to maintain our terrestrial ecosystem of the Earth. Especially, climate changes, global warming, clean water, valuable ecosystem

goods and humanity directly depend on forests [1–5]. Forests are also a central factor for the global carbon cycle and atmospheric carbon sinks or sources [6]. Forests are capable of stabilizing atmospheric carbon dioxide concentrations thereby mitigating global warming and climate change [7, 8]. Forest resources have been shrinking faster over the last few decades. As a consequence, the threat to ecosystem as an essential life-support system is also potentially rising. Therefore, it is crucial to study the forest ecosystem to mitigate the above concerns due to the same. The global observation systems and analysis techniques are improving rapidly worldwide to study, monitoring, mapping and understand the forests ecosystem. Remote sensing is one of the fastest and cost-effective geo-spatial monitoring and mapping techniques useful in investigating and observing natural resources. Applications include forest monitoring and recording forest biomass on climate change mitigation and planning for maintaining balance for ecosystem services. The monitoring forests and estimation of forest biomass using satellite data has received increasing attention for many reasons globally. Accurate forest above-ground biomass (AGB) assessment is crucial for sustainable forest management and mitigation processes and to recognize climate change scenario due to deforestation. Biomass assessment via remotely sensed data of a large region is one the cost effective and eco-friendly application of remote sensing technology. Remotely sensed data from the recently launched satellites confer for better ecosystem models and improved land-based inventory systems. The above datasets and improved techniques allow better assessment of forest canopy height, estimation of forest AGB, and carbon stocks [1–5]. At the present time optical remote sensing data are freely available at a global scale. However, the satellite image processing and analysis for quick, accurate and precise forest above ground biomass (AGB) evaluation are still challenging and difficult. Accurate forest aboveground biomass (AGB) assessment is crucial for sustainable forest management to recognize possible climate change and deforestation for mitigation processes.

The Copernicus programme, an Earth observation programme of the European Union aims at achieving a global, continuous, autonomous, high quality, wide range Earth observation capacity [9]. The Copernicus Sentinel missions are collecting a number of data including Sentinel 1 (microwave) and Sentinel 2 (optical) for mapping and monitoring applications [10]. The availability of Sentinel 2 imagery at high spatial resolution (10 m to 60 m) offers a new opportunity to study and assessment for the above-mentioned challenges. Generally, remote sensing techniques do not derive forest biomass directly, but use parameters that are related to forest above ground biomass such as forest height, leaf area index, fraction of vegetation cover (FVC), or net primary production. Because of established relationships with AGB, these parameters or variables are widely incorporated into the mapping of forest AGB. Different methods have been developed to estimate forest biomass with remote sensing and ground data, based on passive and/or active instruments [1–5]. Active sensors, such as light detection and ranging (LiDAR) and synthetic aperture radar (SAR), have the advantage to penetrate the canopy; for this reason, they are considered the most useful tools for providing vertical structure or volumetric forest measures. Passive sensors, such as optical Sentinel 2 provides the vegetation surface cover, spread and chlorophyll contents and FVC in estimation of AGB [11]. Canopy height estimation using multifrequency and multi-polarization Radarsat-1 and Sentinel-1 images over hilly forested areas have also been

shown to provide significant improvement in AGB evaluation [12]. The top of the canopy digital surface model (TCDSM) also proved to be one of the important parameters. In forest management, carbon storage assessment, and forest stand height measurement.

Tree height is an ecological parameter in its own right and also an important input to the tree growth simulation models [13]. Further, there are several improvements in the data processing and classification techniques have been developed for forest monitoring and mapping using the above datasets (e.g., Sentinel-2) [1–5].

This research aims to apply recently launched optical Sentinel 2 satellite data, collected on December 4, 2019 for estimation of FVC in order to estimate forest above ground biomass. Ground truth data from 22 ground locations with 30 m by 30 m plot size were collected between September 4, 2019 to September 30, 2019 for forest FVC and above ground biomass measurements. In this study, vegetation indices and FVC from Sentinel 2 were calculated and validated with ground truth in order to measure accurately AGB from Tundi reserved forest, Jharkhand, India. The study demonstrated encouraging results in calculated FVC in forest AGB mapping using the freely accessible and high-resolution Sentinel 2 data.

2 Study Area and Datasets

Description of the study area and data details are provided in brief in the following subsection.

2.1 Study Area

In this experiment, Tundi reserved forest in the Dhanbad district of Jharkhand state, India is selected as a study area. There are few isolated hills of varying dimensions scattered in the northern half in this district. The study area covers 144 km², and ranges between the latitude 23° 52' 57.37" N - 23° 59' 44.62" N and longitude 86° 12' 13.49" E - 86° 30' 58.28" E. The type of forest is deciduous and consists of *Shorea robusta* commonly known locally as “Sal” as the most predominant tree species. Overall forest composition and nature is mixed and the top storey of the forest is with average height around 12 m and maximum height up to 20 m. The test site is dominated by minor hillocks with undulating topography.

The area receives typical monsoon type climate with three marked seasons, the hot, the rainy and winter. Humidity is very high during the rainy season and very low during the hot weather. The hot season extends from February to middle of June. The maximum temperature rises above 45 °C and hot wind known as “Loo” blows frequently during April to June till onset of monsoon. Thunderstorms usually occur in May, accompanied by a temporary fall in temperature by few degrees. Due to heavy industrialization and mining activities, lot of suspended particles and specks of dusts are found in the atmosphere during this season. The monsoon usually breaks in the middle of June and continues till the end of September. The average rainfall is between 1100 mm to 1200 mm.

2.2 Datasets

The Sentinel 2 multi-spectral image (MSI) Level 1C data collected on December 4, 2019 have been used to assess FVC in this study. The multispectral bands with spatial resolution of 10 m and 20 m were used after resampling to 10 m. The data details are displayed in Table 1. Further, study sites were visited, and ground truth (GT) samples from 22 different locations were collected. The ground measurement for tree heights, and FVC estimate were done.

Table 1. Bands specifications and spectral range of the Sentinel 2 system.

Sub-system	Band number	Wavelength range (μm)	Band central wavelength (μm)	SR(m)
VNIR	1	0.43–0.45	0.443 (Coastal aerosol)	60
	2	0.46–0.52	0.490 (blue)	10
	3	0.54–0.58	0.560 (green)	
	4	0.65–0.68	0.665 (red)	
	5	0.70–0.71	0.705 (Vegetation red edge)	20
	6	0.73–0.75	0.749 (Vegetation red edge)	
	7	0.77–0.79	0.783 (Vegetation red edge)	
	8	0.78–0.90	0.842 (NIR)	10
	8a	0.86–0.88	0.865 (Vegetation red edge)	20
	9	0.93–0.95	0.945 (Water vapor)	60
10	1.37–1.39	1.375 (SWIR – Cirrus)		
SWIR	11	1.57–1.66	1.610 (SWIR)	20
	12	2.10–2.28	2.190 (SWIR)	

Note: SR = spatial resolution; VNIR = visible/near infrared; SWIR = shortwave infrared

3 Proposed Method

The proposed approach to calculate FVC from sentinel 2 is applied in the following sequential steps.

Step 1. In this step, preprocessing is performed on raw data for radiometric calibration and noise reduction from radiance data. Further, atmospheric correction is performed for eliminating the atmospheric effects and converting radiance data into reflectance data. Furthermore, spatial resampling is performed to bring all the bands of the dataset into similar spatial resolution.

Step 2. In this step, vegetation index (VI) is calculated. In this work three different vegetation indices are calculated to compare the vegetation indices for finding the best among

the available indices in FVC calculation. The three different vegetation indices: normalized difference vegetation index (NDVI), normalized difference index 45 (NDVI45), and inverted red-edge chlorophyll index (IRECT) are calculated from Sentinel 2 reflectance data as below.

$$NDVI = \frac{(Band8 - Band4)}{(Band8 + Band4)}. \quad (1)$$

$$NDI45 = \frac{(Band5 - Band4)}{(Band5 + Band4)}. \quad (2)$$

$$IRECI = \frac{(Band7 - Band4)}{(Band5/Band6)}. \quad (3)$$

Suppose the above indices are represented as VI_i , where $i = 1:3$, technique for vegetation index calculation. Thus, $VI_1 = NDVI$, $VI_2 = NDI45$, and $VI_3 = IRECI$.

The following process from step 3 to step 5 is applied on each vegetation index individually.

Step 3. In this step, the calculated vegetation indices values are rescaled to 0–1 from each vegetation index individually, as below.

$$VIR = \frac{VI - VI_{min}}{VI_{max} - VI_{min}}, \quad (4)$$

where, VIR is the rescaled vegetation index value, VI is the vegetation index value, VI_{min} , is the minimum vegetation index value and VI_{max} is the maximum vegetation index value.

Further, a threshold vegetation index value (e.g., $VIR = 0.5$ in this paper) was chosen to distinguish vegetated and non-vegetated pixels in the image.

Step 4. In this step, ratio of vegetated and non-vegetated area with respect to the area of entire study area is calculated. According to the threshold vegetation index chosen in the above step (e.g., 0.5), pixel values more than threshold are counted as vegetated and less than threshold are counted as non-vegetated pixels.

Let us consider total number of pixels in the image is N_{total} and number of vegetated and non-vegetated pixels are $N_{vegetation}$ and $N_{non-vegetation}$, respectively. Then ratio of vegetation ($R_{vegetation}$) and non-vegetation ($R_{non-vegetation}$) areas with respect to entire area are calculated as:

$$R_{vegetation} = \frac{N_{vegetation}}{N_{total}} \text{ and } R_{non-vegetation} = \frac{N_{non-vegetation}}{N_{total}}. \quad (5)$$

Step 5. In this step, the FVC image is generated using the following steps.

The average vegetation index value from vegetated pixels and non-vegetated pixels are calculated as $AVI_{vegetation}$ and $AVI_{nonvegetation}$ respectively. Further, normalized AVI (NAVI) is calculated from the vegetated and non-vegetated pixels as below.

$$\begin{aligned} NAVI_{vegetation} &= R_{vegetation} \times AVI_{vegetation}, \text{ and} \\ NAVI_{non-vegetation} &= R_{non-vegetation} \times AVI_{non-vegetation}. \end{aligned} \quad (6)$$

The FVC is generated as below.

$$F_{vegetationcover} = \frac{VIR - NAVI_{non-vegetation}}{NAVI_{vegetation} - NAVI_{non-vegetation}}. \quad (7)$$

The above model represents the connection of vegetation fraction with VI in the image.

The $NAVI_{vegetation}$ and the $NAVI_{nonvegetation}$ represent the influences of vegetation and non-vegetation in the image pixels.

The above procedure from step 3 to step 5 is repeated individually for each vegetation index generated from the Sentinel 2 image. Suppose vegetation indices images after rescaling are represented as $VIR_i(x,y)$, where $i = 1:3$; is the technique for generation of vegetation indices (e.g., 1 = NDVI, 2 = NDI45, and 3 = IRECI in this paper), and (x,y) is the location of the image pixel, then the general equation for FVC from vegetation indices are represented as below.

$$F_i^{vegetationcover}(x, y) = \frac{VIR_i(x, y) - NAVI_i^{non-vegetation}}{NAVI_i^{vegetation} - NAVI_i^{non-vegetation}}. \quad (8)$$

The effectivity of the above approach was tested on Sentinel 2 image from the study area using three vegetation indices namely NDVI, NDI45 and IRECI.

4 Results and Discussion

The above developed approach was applied on Sentinel-2 as an optical remote sensing image to calculate the FVC in order to calculate forest AGB from Tundi reserved forest, Jharkhand, India. The results are shown in Fig. 1.

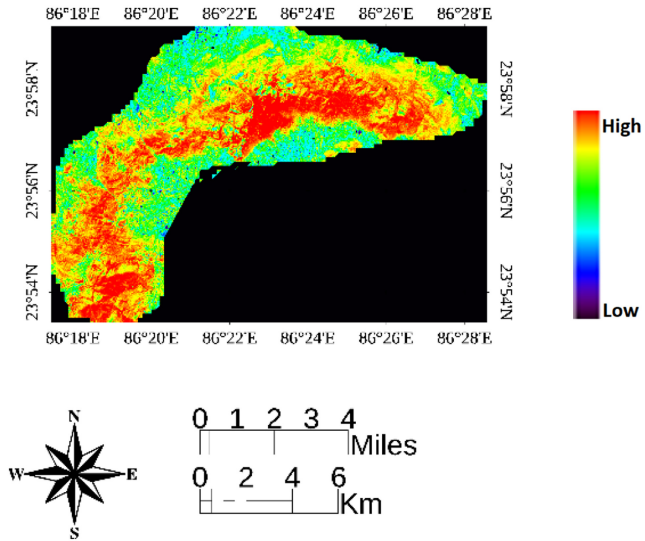
Initially, vegetation indices have been calculated to get the information of vegetation amount at each pixel in the image using NDVI (Fig. a (1), NDI45 (Fig. a (2), and IRECI (Fig. a (3) respectively. Subsequently, the developed approach was applied on each vegetation indices to calculate corresponding FVC images (NDVI (Fig. b (1), NDI45 (Fig. b (2), and IRECI (Fig. b (3)).

Additionally, we have collected 22 ground field data with 30 m by 30 m plot size and associated FVC were calculated from the corresponding plots. The sampling sites on the ground were carefully chosen to truly represent the varying conditions of the entire forest diversity of the study area.

To verify the accuracy of FVC results calculated from Sentinel 2, we have rescaled the calculated FVC between 0–1 for both ground truth and the Sentinel 2 data. The results revealed that ground based calculated FVC matched with image FVC with varying degree of accuracy with respect to vegetation indices. The image FVC with respect to ground FVC within one standard deviation are 15, 17, and 20 among 22 points by NDVI, NDI45 and IRECI respectively. The results show that our approach for calculation of FVC from Sentinel 2 produces accuracy of more than 68% for NDVI, 77% for NDI45 and 90% for IRECI based estimations. Thus, the IRECI performs best among the three vegetation indices used in this paper. The results reveal that Sentinel 2 data, combined with the

(a)

(1)
NDVI Map



(2)
NDI45 Map

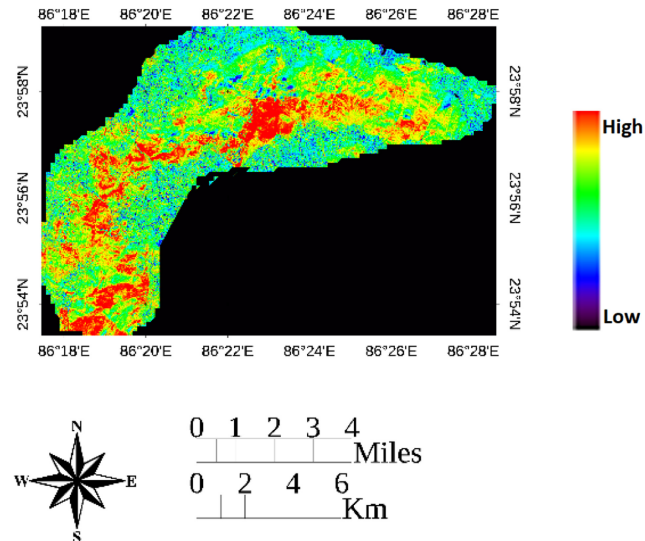
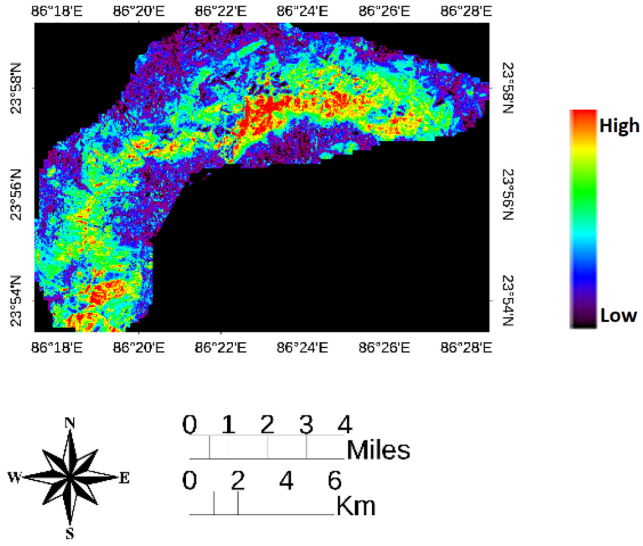


Fig. 1. (a) Vegetation indices image, and (b) corresponding FVC image determined by proposed approach using NDVI (1), NDI45 (2) and IRECI (3) from the study area.

(3)
IRECI Map



(b)

(1)
FVC_NDVI Map

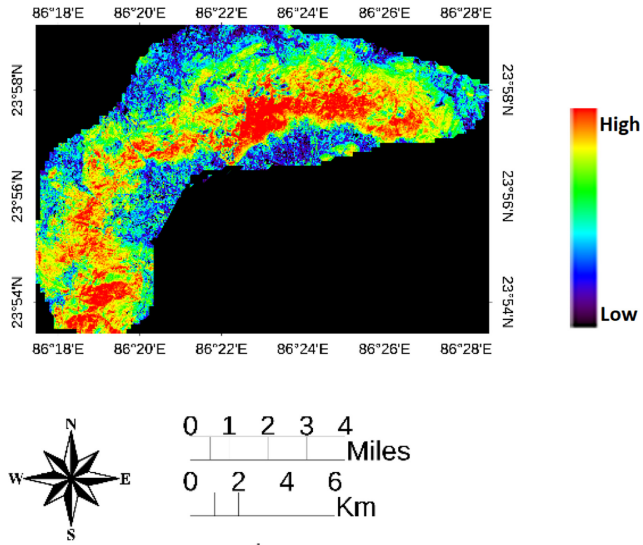
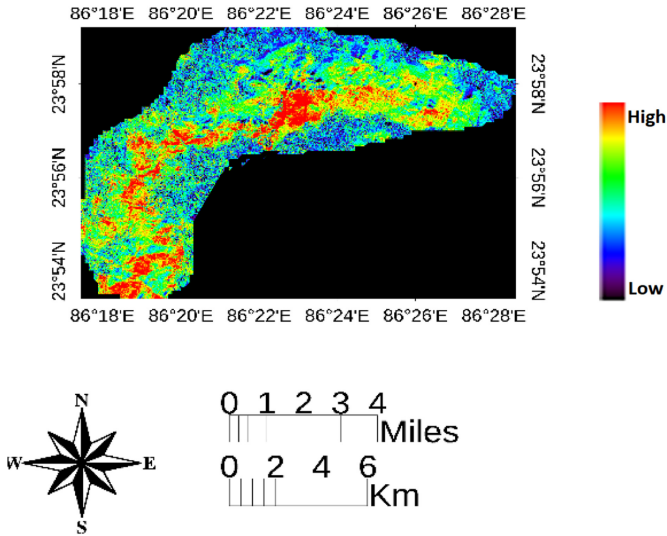


Fig. 1. (continued)

(2)
FVC_NDI45 Map



(3)
FVC_IRECI Map

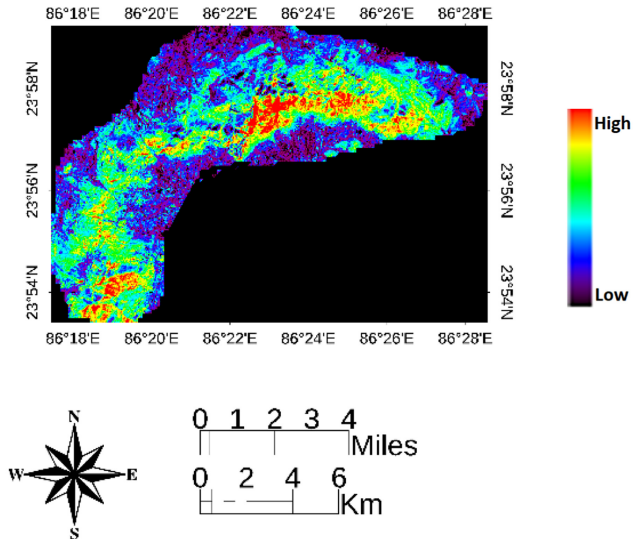


Fig. 1. (continued)

developed approach, can be used to monitor forest vegetation expansion and health at high spatio-temporal resolution with improved accuracy.

A linear regression between ground based calculated AGB and FVC will be developed in future work to find a general relationship between FVC and AGB. This work will provide the insight for obtaining AGB dynamics at a fine spatial and temporal resolution with optical remote sensing data.

5 Conclusion

An improved approach for FVC estimation from vegetated terrain has been developed. The method has been implemented mainly in four steps involving vegetation index calculation to quantify the amount of vegetation at each pixel of the image, vegetation index rescaling between 0 to 1, computing the ratio of vegetated and non-vegetated area with respect to the entire survey area, and finally, FVC calculation from rescaled vegetation index and proportion of vegetated and non-vegetated fraction of the image. The developed approach was applied to map FVC using Sentinel 2 from Tundi reserved forest, Jharkhand, India. The results were verified and validated with ground truth demonstrating accuracy of roughly 90%. As a further scope of the work, a model shall be developed for directly calculating forest AGB from FVC using Sentinel 2 in our future research work. Relationship between AGB calculated from ground truth and FVC calculated from Sentinel 2 shall be established to find a general model.

References

1. Agata, H., Aneta, L., Dariusz, Z., Krzysztof, S., Marek, L., Christiane, S., Carsten, P.: Forest aboveground biomass estimation using a combination of sentinel-1 and sentinel-2 data. In: IGARSS 2018–2018 IEEE International Geoscience and Remote Sensing Symposium, pp. 9026–9029. IEEE, July 2018
2. Chen, L., Ren, C., Zhang, B., Wang, Z., Xi, Y.: Estimation of forest above-ground biomass by geographically weighted regression and machine learning with Sentinel imagery. *Forests* **9**(10), 582 (2018)
3. Frampton, W.J., Dash, J., Watmough, G., Milton, E.J.: Evaluating the capabilities of Sentinel-2 for quantitative estimation of biophysical variables in vegetation. *ISPRS J. Photogramm. Remote Sens.* **82**, 83–92 (2013)
4. Nuthammachot, N.A., Phairuang, W., Wicaksono, P., Sayektiningsih, T. Estimating Above-ground biomass on private forest using sentinel-2 imagery. *J. Sens.* (2018)
5. Zhang, Y., Liang, S., Yang, L.: A review of regional and global gridded forest biomass datasets. *Remote Sensing* **11**(23), 2744 (2019)
6. Timothy, D., Onesimo, M., Cletah, S., Adelabu, S., Tsitsi, B.: Remote sensing of aboveground forest biomass: a review. *Tropical Ecol.* **57**(2), 125–132 (2016)
7. Lu, X.T., Yin, J.X., Jepsen, M.R., Tang, J.W.: Ecosystem carbon storage and partitioning in a tropical seasonal forest in Southwestern China. *Ecol. Manage.* **260**, 1798–1803 (2010)
8. Qureshi, A., Pariva, B.R., Hussain, S.A.: A review of protocols used for assessment of carbon stock in forested landscapes. *Environ. Sci. Policy* **16**, 81–89 (2012)
9. ESA: Copernicus, Overview. ESA. 28 October 2014. Accessed 26 Apr 2016
10. Gomez, M.G.C.: Joint use of Sentinel-1 and Sentinel-2 for land cover classification: A machine learning approach. Lund University GEM thesis series (2017)
11. Zhang, S., Chen, H., Fu, Y., Niu, H., Yang, Y., Zhang, B.: Fractional vegetation cover estimation of different vegetation types in the Qaidam Basin. *Sustainability* **11**(3), 864 (2019)

12. Kumar, P., Krishna, A.P.: Forest biomass estimation using multi-polarization SAR data coupled with optical data. *Curr. Sci.* **119**(8), 1316–1321 (2020)
13. Kumar, P., Krishna, A.P.: InSAR based Tree height estimation of hilly forest using multi-temporal Radarsat-1 and Sentinel-1 SAR data. *IEEE J. Selected Topics Appl. Earth Observ. Remote Sens.* **12**(12), 5147–5152 (2019)