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ESTIMATION OF ABOVEGROUND FOREST BIOMASS USING GEOSPATIAL TECHNIQUES IN MURREE AND ABBOTTABAD AREAS, PAKISTAN

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ABSTRACT

Aboveground biomass (AGB) is an important biophysical parameter for evaluating global carbon stocks. Accurate estimates of AGB are gaining importance because of UN Climate Change requirements. This research study developed a methodology for estimating aboveground forest biomass using SPOT-5 satellite data coupled with sample field data and allometric equations in the coniferous forests of Murree and Abbottabad areas, Pakistan. Plot sizes of 13.7 m radius were used for field measurements, size of plots were based on tree density of the forest in the study area. In total, 11 sample plots were surveyed for measurements of tree Diameter at Breast Height (DBH), tree density and species information. Biomass values were worked out using volume equations, factors in the study areas. Normalized Difference Vegetation Index (NDVI) values were extracted from radiometrically and atmospherically corrected SPOT-5 data. The algorithm was developed between NDVI and measured tree biomass for estimating and generating biomass maps for the study areas. The spectrally derived above ground biomass were estimated as 235 Mega g/ha and 261 Mega g/ha in Murree and Abbottabad areas, respectively. The AGB results in this study have been comparable with previously reported values in the area. The study demonstrates the application of geospatial technologies including mapping, spectral responses and field measurements for biomass estimation. The forest maps so generated provide a new method of assessing forest AGB resource in the study areas. To further improve efficiency of regression models for precise measurements of AGB, the bigger number of sample sites could be taken into consideration.

Keywords: biomass, coniferous, reflectance, vegetation indices, geospatial, SPOT-5

INTRODUCTION

In estimating the global carbon, forests are recognized as the significant components. Terrestrial carbon stocks comprise 80% aboveground forest biomass and 20% belowground biomass (Wani *et al.*, 2015). The Above Ground Biomass (AGB) is the largest pool of stored carbon which is directly impacted by depletion in forests.

In the framework of climatic changes at national and international level, forest biomass estimation for carbon management is considered as an essential activity. Therefore, it becomes vital to evaluate regional forest biomass in the context of climate change. Reducing emissions from deforestation and degradation (REDD+) agenda of United Nations is already considering the role of forests in mitigating climate change in developing countries (UNFCCC, 2008).

The most accurate method to estimate AGB is to cut down all the trees in an area, dry them and then measure the weight of the leaves, branches and trunks of all the trees. However, they are difficult to conduct even in inaccessible areas, time consuming, laborious and expensive. On the other hand, Satellite Remote Sensing due to its synoptic and repeated coverage is a viable solution for mapping and monitoring of AGB at regional and global scale. With the advancements in capabilities of space borne sensors, modus operandi of forest biomass estimation using Satellite Remote Sensing data and GIS techniques have been evolved very rapidly as compared to traditional field based methods (Franklin 2001, Lu 2006, Lutz *et al.*, 2008, Goetz *et al.*, 2009, Saatchi *et al.*, 2011, Psomas *et al.*, 2011, UN-REDD, 2016).

Very few studies have been conducted in Pakistan till to date which employed Remote Sensing and GIS techniques for estimation of forest biomass. Mehwish *et al.* (2015) estimated biomass as 251 Mega g/ha using SPOT 5 data in conjunction with field data in moist temperate forest of Bhurban Forest during 2010-2011. Also, a research study was conducted for forest AGB estimation in Chichawatni plantation, Punjab using optical high-resolution (WorldView, GeoEye) and SAR (ALOS-1/2 PALSAR) remote-sensing data coupled with field measurements and allometric equations (ICIMOD, 2015).

This paper presents tree biomass assessment for coniferous forests of Murree (sub-tropical pine) and Abbottabad (moist temperate) areas of Pakistan. This study was aimed to investigate the relationship between field measured biomass and values derived from vegetation indices (estimated from satellite remote sensing data) to develop algorithm for estimating AGB and generate a spatially explicit aboveground forest biomass (AGB) map for the study areas.

MATERIALS AND METHODS

Study area

The two study areas were selected for estimation of tree biomass using satellite data located in Punjab and Khyber Pakhtunkhwa (KP) provinces of Pakistan. Study area I contains Chir pine forest whereas; study area II contains moist temperate forest. The main aim for selection of these two distinct study areas was to collect information of major tree species of conifer forest in Northern part of Pakistan namely, Chir pine, Blue pine, Deodar and Fir. Sharma *et al.* (2010) concluded in the study that that most of the broadleaved forest types have higher carbon stocks than coniferous types and estimated AGB as 101.42–434.43 Mg/ha in Garhwal, North-West Himalaya, India.

The recorded forest areas of Rawalpindi and Abbottabad Districts are 113,159 ha and 67,173 ha, which constitute 21.8% and 37.6% of its geographical area respectively (Bukhari., 2012). Out of which sub-tropical Chir pine covers 5.3% in Rawalpindi District and 26.3% is covered by moist temperate forest in Abbottabad Districts (Bukhari , 2012).

Study area I located at Seri Bari Reserved Forest (from 33°50'36.18''N, 73°24'41.67''E to 33°55'27.60''N, 73°18'47.96''E) near Ghora gali, Murree and it belongs to sub-tropical Chir Pine forest. This forest type is open, inflammable and often without shrub layer (Bukhari., 2012). The study area is part of Western Himalaya and within the range of the south-west summer monsoon. It is a mountainous region with an average elevation of 1600 m approximately. Overall Murree has moderate to steep slopes (WWF-P, 2013). Murree receives 1789.2 mm of rainfall per year. The dominant species found in the study area is Chir pine (*Pinus roxburghii*). In total six sampling plots were placed in study area I starting from lower part up to higher elevations. As shown in Figure1 three sampling plots were placed at the right corner and three were placed at the left corner. The ground view of the study area I is shown in Figure 2.

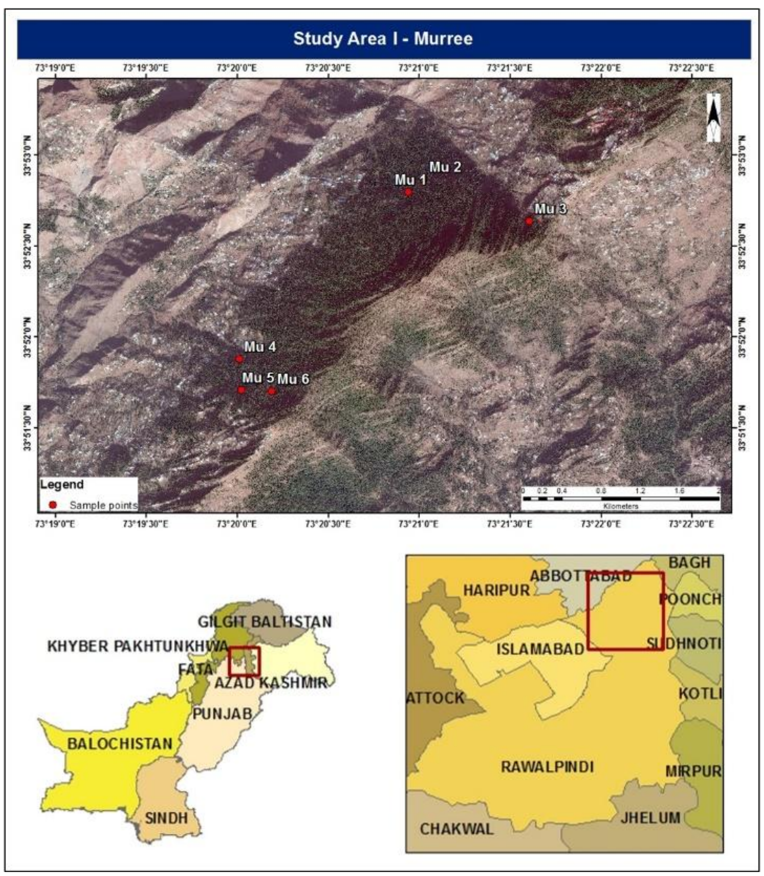

Fig. 1. Location Map of Study Area I with survey plots.

Fig. 2. Ground View of Study Area I.

The study area II located near Indar Seri Reserved Forest and Thandiani, Abbottabad (from 34°14'45.77"N, 73°19'1.78"E to 34°11'54.11"N, 73°22'4.71"E) and it belongs to *moist temperate forest*. These forest types are found on gentle slopes with deep soil especially on cool northern aspect. The terrain of the area is rugged at an average elevation of 2300 m approximately, and its location at the base of the Himalayas gives it a temperate climate throughout the year. The average rainfall reaches to 1366.16 mm (IUCN, 2004).

Table 1. Description of the Study Areas.

Location	**Latitude, longitude**	**Average Altitude (m)/rainfall (mm)**	**Forest type**	**Dominant Species**
Murree Hills	34°13'35.56"N, 73°20'7.72"E to 34°13'0.25"N, 73°21'11.90"E	1600 / 1789.2	Sub-tropical Chir-pine	Chir pine (*Pinus roxburghii*)
Thandiani, Abbottabad	34°13'35.56"N, 73°20'7.72"E to 34°13'0.25"N, 73°21'11.90"E	2300 / 1366.16	Moist temperate	Blue pine/Kail (*Pinus wallichiana*), Fir (*Abies pindrow*) and Deodar (*Cedrus deodara*)

Fig. 3. Ground View of Study Area II.

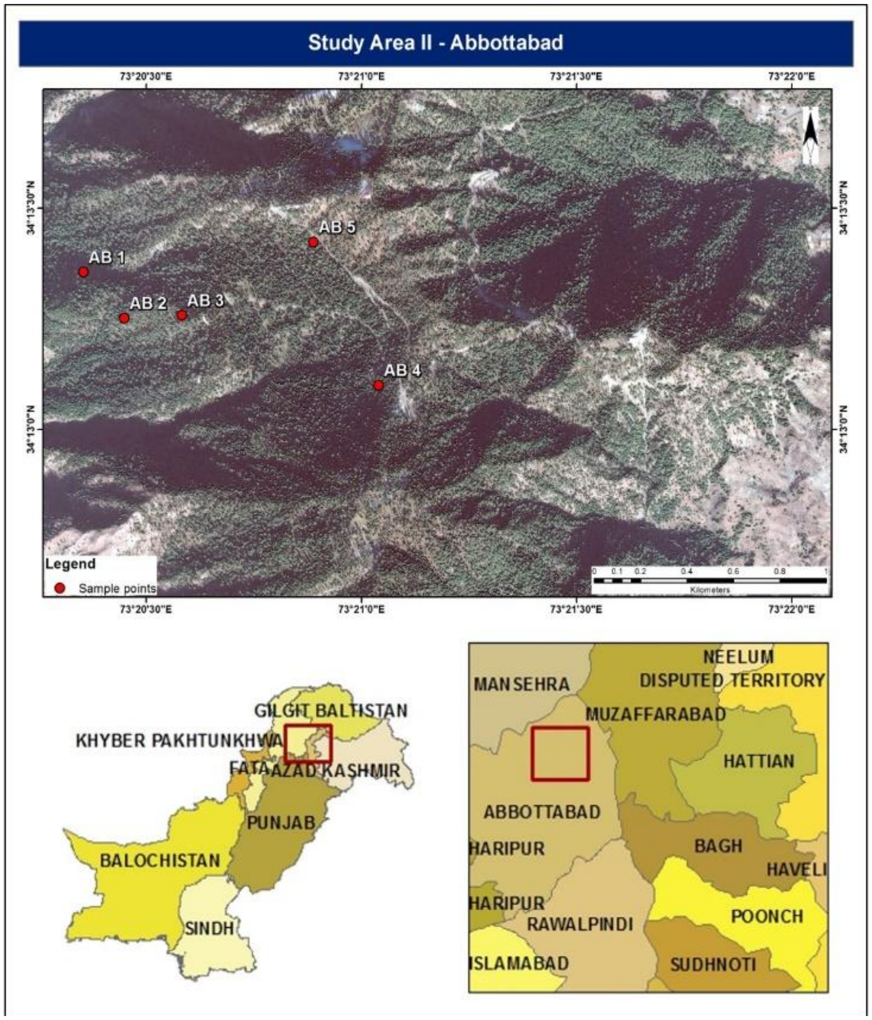

Fig. 4. Location Map of Study Area II.

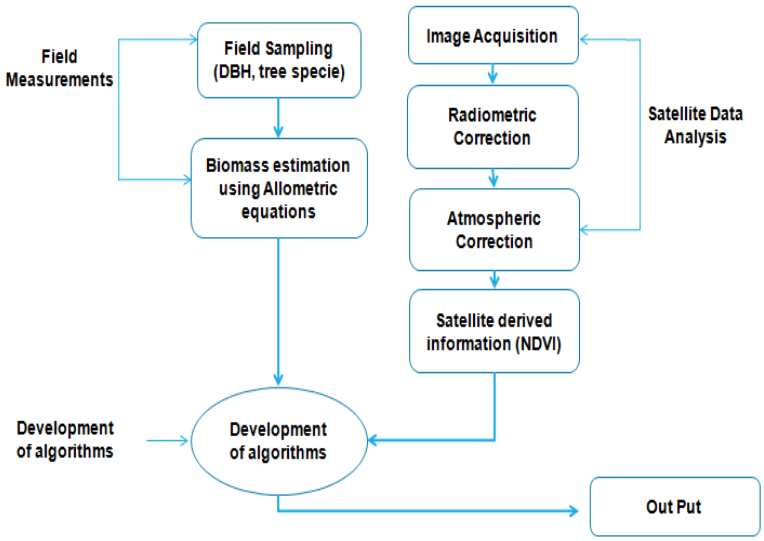

Fig. 5. Methodology of Estimating AGB (Mg/ha) using SPOT-5 data and field measurements, in the Murree and Abbottabad areas of Pakistan.

The dominant species in study area II are Blue pine/Kail (*Pinus wallichiana*), Fir (*Abies pindrow*) and Deodar (*Cedrus deodara*). The Fir is found at the highest altitudes, deodar and Kail at intermediate heights and Chir in the lower regions (Khan, 2002). In total five sampling plots were placed in the study area II starting from lower part up to higher altitudes in similar manner as in study area I. Figure 4 shows the location map of the study area II along with sampling point locations. Figure 3 showed the ground view of the study area.

Field Measurements

While, there is no method to directly estimate forest AGB from remotely sensed data, it can be estimated by developing the relationship between satellite-derived variables and biomass derived from field data. Thus, as shown in Figure 5, field visits were carried out for onsite measurements.

Field measurements were carried out in the month of July, 2014. Systematic sampling approach was adopted because of paucity of funds for sampling. In total, 11 plots were sampled from two study areas as mentioned earlier. The position of each plot was located using hand-held global positioning system (GPS) unit. All the plots were circular with the radius of 13.7 m. In each plot, the trees were sampled for diameter at breast height (DBH), distance from center point and angular placement from the north. The trees that have DBH lower than 10cm were considered as regeneration. Additional information of each plot includes slope, aspect and altitude. Figure 6 showed view of field measurements taken from both study areas.

Fig. 6. Field Sampling.

Biomass Estimations using Field Data

AGB (Mega g/ha) is defined in this study as biomass of trees greater than 10 cm DBH including tree foliage and branches. The data collected from plot samples was used to calculate tree biomass using allometric equations and biomass expansion factor (BEF). These equations may include information on trunk diameter D (in cm), total tree height H (in m) and wood specific gravity r (in g/cm^3) (Chave *et al*., 2005). The development of allometric equations for tree species is a challenging task and it involves cutting of the whole tree (Chave *et al.*, 2005). Due to current situation of forest in Pakistan it is not recommended that for each study separate allometric equations would be developed. Keeping in mind this fact Pakistan Forest Institute PFI, Peshawar was contacted for the allometric equations. The allometric equations provided by PFI that were used for calculating species-wise tree biomass is,

$$\text{Volume (Tree)} = a + b * H + c * D^2 + e * D^2 * H \quad \text{(Eq.1)}$$

where,

H = Tree height; D = Diameter at Breast Height

The estimated volume from tree allometric equations was subsequently converted into tree biomass using tree density and biomass expansion factor in the following equation

Biomass (tree) = Volume x Tree density x Biomass Expansion Factor (Eq.2)

(Biomass Expansion Factor is either derived from field – plot measurement or forest inventory data. Tables of these are obtained from Forestry Department (see Franklin *et al.*, 2001).

Satellite Data Analysis

SPOT-5 data has been used in this study for developing regression equation between tree biomass and Normalized Difference Vegetation Index (NDVI). Table II shows details of satellite data used in this study.

Table 2. SPOT-5 scenes used to map AGB in the Study Areas.

S.No	**Scene No**	**Projection/ Datum**	**No. of Bands**	**Spatial resolution**	**Acquisition date**
1	196-281	UTM/WGS 84 zone 43N	4	2.5 m	20-09-2013
2	196-282	UTM/WGS 84 zone 43N	4	2.5 m	20-09-2013

Preprocessing of Satellite Imagery

Satellite datasets used in this study were corrected atmospherically using ENVI 5.0 software. Firstly, the data was corrected radiometrically and then reflectance was calculated (Zheng *et al*., 2004). Following are the two steps used for the preprocessing of SPOT-5 imagery.

i. Conversion of DN to Radiance

The general equation for DN to Radiance is as follows

$$L = Gain * Q_{CAL} + Bias \quad \text{(Eq. 3)}$$

where,

L = Spectral Radiance at the sensor's aperture ($W/m^2/sr/\mu m$)

Gain = Rescaled gain

Q_{CAL} = Digital Number (DN)

Bias = Rescaled bias

The Gain and Bias information was collected from metadata file.

ii. Conversion of Radiance to Top of Atmospheric (TOA) reflectance

Radiance was converted in TOA reflectance using following equation

$$R = \frac{\pi * L * D^2}{ESUN * COS\theta} \quad \text{(Eq. 4)}$$

where,

R = Unitless planetary reflectance

L = Spectral radiance at the sensor's aperture

D = Earth-Sun distance in astronomical units

E_{SUN}= Mean solar exo-atmospheric irradiances

θ = Solar zenith angle

Normalized Difference Vegetation Index

Normalized Difference Vegetation Index (NDVI) was estimated using the reflectance of Near Infrared (NIR) band and Red band (Rouse *et al.,* 1974). In SPOT-5 data band 3 is NIR band and band 2 is the red band so the formula to calculate NDVI using SPOT-5 data is

$$NDVI = \frac{\text{Near Infrared} - \text{Red}}{\text{Near Infrared} + \text{Red}} \quad \text{(Eq. 5)}$$

Spectral indices were calculated using radiometrically and atmospherically corrected wavelength bands 3 and 2 of SPOT-5 data. Spectral indices were calculated using reflectance of wavelength bands because algebraic operations such as ratio of reflectance reduce the noise effect and enhances the spectral signals (Lei *et al.*, 2012, Psomas *et al.,* 2011, Lu, 2005).

Regression analysis and spatial AGB estimation

Regression method was used to estimate AGB by establishing a correlation between biomass calculated from field data and the SPOT-5-derived vegetation indices. The NDVI responds to both the over story and understory vegetation (Chen and Cihlar, 1996). In this study, AGB was estimated in relation to NDVI based on the following relationship

$$AGB\ (ha) = 368\ NDVI + 0.7 \qquad (Eq.\ 6)$$

S.E = 11.47, R^2 = 70.9%, p-value = 0.009

Where, AGB and NDVI are response and predictor variables respectively. Each sample in the regression algorithm reflects the measured AGB of trees per plot.

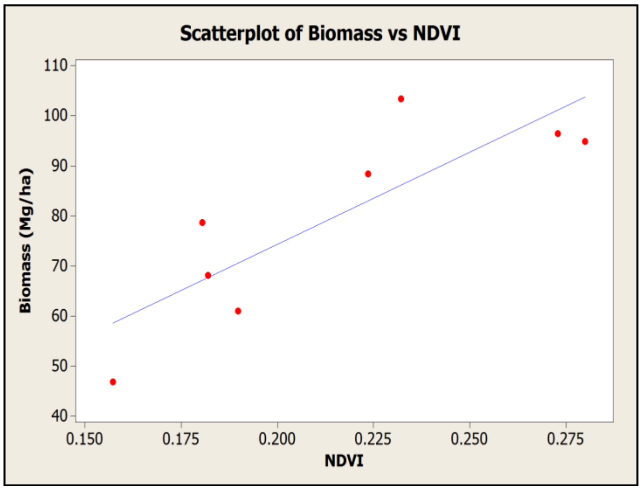

Fig. 7. Scatterplot of algorithm using NDVI as predictor.

Spatial Estimation of AGB

The regression algorithms were applied to the NDVI images to produce total AGB maps for the Murree and Abbottabad study areas. The SPOT-5imageswere acquired in September 2013 (Table 2) for mapping AGB, and the field survey was carried out in July 2014. Field surveys were carried out in July 2014 because of suitable weather conditions. Since there was a normal weather variation between image acquisition and field survey period, thus an assumption was made that for this ten month period, the total AGB remained relatively constant.

RESULTS AND DISCUSSION

Most of the developing countries do not have forest inventory data to get accurate AGB figures. Geospatial techniques that make use of combination of regression models, vegetation indices, and canopy reflectance models have been established their role to obtain accurate AGB quantities over larger areas in a cost effective and efficient manner. Also, these methods attracted scientists due to accuracy as well as fast processing and mapping capability of large quantities of data in digital format.

Multispectral satellite data or derived values (e.g. vegetation indices, mixture fractions) are empirically related to forest stand structure and biomass (Gerylo *et al.,* 2002, Hall *et al.*, 2006, Wulder, 1998). Normalized difference Vegetation Index was developed by Rouse *et al.* (1974) quantify vegetation conditions and estimation of biomass over large areas. It was also shown by Tucker (1979), that green biomass can be indicated through ratio of infrared and red. In Japan (Lee and Nakane, 1997), biomass was estimated using Landsat TM based various vegetation indices and concluded that biomass of pine stands could be estimated using NDVI in the best manner. NDVI is the most extensively used vegetation index (Lei *et al.*, 2012, Heiskanen, 2006, Patil *et al.*, 2015). Das and Singh (2012) reported that NDVI is the ratio of contrasting reflectance between maximum reflectance of infrared wavelength owing to leaf cellular structure and maximum absorption of red wavelength due to chlorophyll pigments. Soudani *et al*. (2006) highlighted the differences in calculating NDVI from different image processing levels such as digital numbers, at-sensor radiances, TOA reflectance which incorporate different sensor and atmospheric parameters.

The NDVI values were retrieved from SPOT-5 images for the two study areas. According to the analysis, the NDVI values ranged from -0.87 to 0.69, pertaining to different types of land use/land cover in Study Area I (Murree), pertaining to different types of land use/land cover including hill shadow i.e. bare land, sparse vegetation, dense forest, and settlements. However, detailed analysis revealed that NDVI values for trees in the study area ranged from 0.24 to 0.49. It is also evident from the analysis that NDVI values were high in central part of the study area and relatively low in the eastern and western part of the image (Fig. 8).

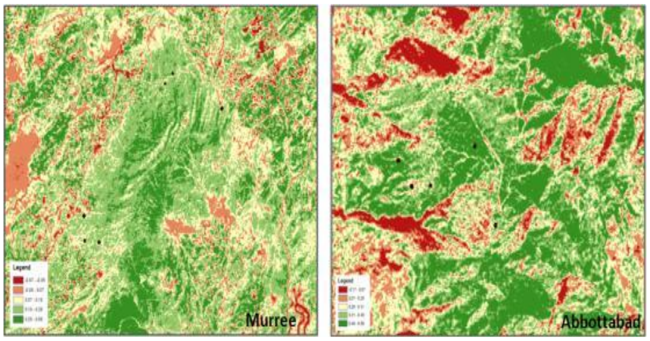

Fig. 8. NDVI images derived from SPOT-5 data of Murree and Abbottabad study areas.

NDVI values in the Study Area II (near Abbottabad) ranged from -0.17 to 0.58, pertaining to different types of land use/land cover including hill shadow i.e. bare land, sparse vegetation, dense forest and settlements. However, NDVI values for tree cover ranged from 0.40 to 0.51.

The final AGB maps resulted from the study were shown in Figure 9 and 10.The AGB values predicted in the Murree region ranged from 0.7 to 235 Mega g/ha, with a mean value of 86 Mg gm/ha and standard deviation (S.D.) of 23 Mega g/ha. However, the AGB values predicted in the Abbottabad region ranged from 0.7 to 261 Mega g/ha, with a mean value of 99 Mega g/ha and standard deviation (S.D.) of 38 Mega g/ha. These values are in close agreement with the previously estimated tree biomass as 237 Mega g/ha in Ghoragali area by Nizami *et al*. (2009). Also, Singh and Singh (1987) reported that biomass of a larger part of forests (163-787 Mega g/ha) in the central Himalayan region lies in the range of 200-600 Mega g/ha given for many mature forests of the world. Furthermore, Chaturvedi *et al*. (1984) estimated total aboveground biomass of Chir pine forest in central Himalaya region as 172.3 ± 29.8 Mega g/ha. Rana *et al.* (1989) studied Himalayan Pine Forests found at an altitudinal range of 300-2200 m and reported 193 to 782 Mega g/ha of biomass for *P. roxburghii*. According to Rana *et al.* (1989) total tree biomass of *P. roxburghii* was distributed in the stem, twigs, leaves, and roots as 63.23, 11.57, 3.38, 3.21, 18.5%, respectively.

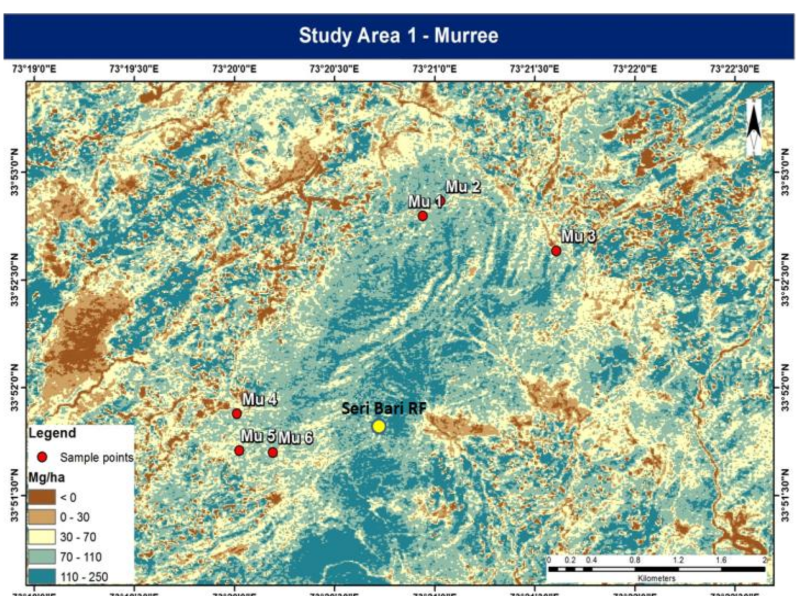

Fig. 9. AGB map (Mega g/ha) of the study area I.

As shown in the Figure 9, the biomass density was higher in the northern and southern parts of Seri Bari Reserved Forest. Whereas, eastern part of Seri Bari Reserved Forest had lower density of forest biomass.

As shown in the Figure 10, the average biomass density in the Abbottabad region was 261 Mega g/ha. The higher values of biomass were found in the eastern part of study area II, near Indar Seri Reserved Forest whereas; eastern part of study area II had lower density of forest biomass.

After comparing forest biomass in both the regions, it was established that forest near Abbottabad region had higher values of forest biomass as compared to Murree region. The increased value of forest biomass in Abbottabad region is due to understory vegetation typically found in moist temperate environment as compared to little or no understory vegetation in sub-tropical Chir pine.

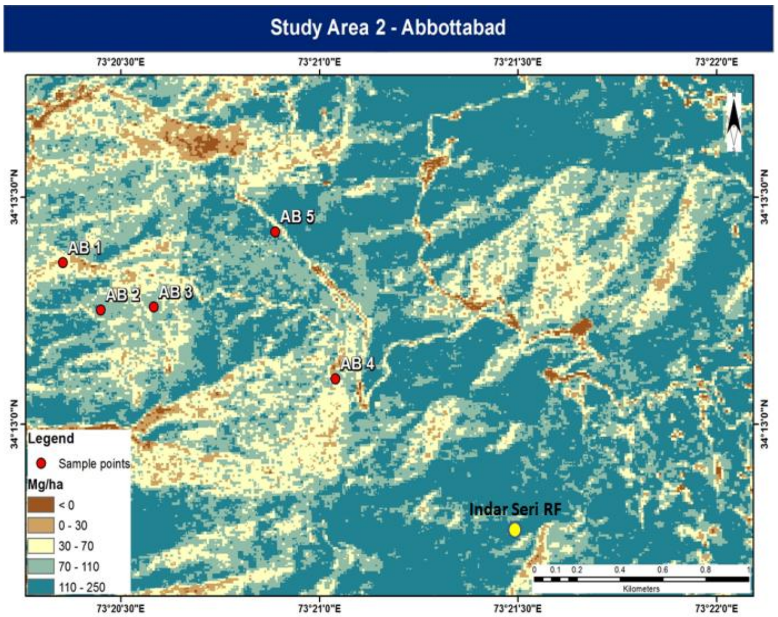

Fig. 10. AGB map (Mega g/ha) of the study area II.

CONCLUSION

The study demonstrates that SPOT-5 data is useful in delineating the spatial distribution of aboveground biomass for the entire extent of the study areas. In addition, it is also evident from the study that SPOT-5 data provides an alternative to extensive field based measurements and allows rapid assessment of aboveground biomass in large areas particularly in inaccessible areas. This method is principally intended for analysts or planners interested in quantifying biomass over extensive forest areas. It was demonstrated that geospatial techniques are viable and efficient solution for forest management which provides up-to-date and timely information.

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