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Carbon emission from deforestation, forest degradation and wood harvest in the temperate region of Hindukush Himalaya, Pakistan between 1994 and 2016

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ABSTRACT

Regional carbon emission related to deforestation, forest degradation, and wood harvest is critical in the development of national action plans and strategies for forest carbon management. In this study, using remote sensed and ground inventory data, deforestation, forest degradation, wood harvest and their integrated carbon losses between 1994 and 2016 in the temperate region of Pakistan were estimated. The present study revealed that deforestation was responsible for a net loss of 629 ha forest (29 ha yr^{-1}), and 4948 ha (245 ha yr^{-1}) forest was degraded. The total harvested wood was 681 km^3 (31 km^3 yr^{-1}). Deforestation was responsible for the loss of 206 kMg C (9 kMg C yr^{-1}), while emissions related to degradation and wood harvest account for 1757 kMg C (80 kMg C yr^{-1}) and 221 kMg C (10 kMg C yr^{-1}), respectively. These findings suggest that an increase in population with the partial protection of forests by policy, weak law enforcement, and cultural attitudes of the local people towards forests were the major drivers of deforestation and degradation between 1994 and 2016, as well as their integrated carbon emissions.

1. Introduction

Forests, the largest carbon sink among terrestrial ecosystem, are important in the process of the global carbon cycle (Coulston et al., 2015; Espírito-Santo et al., 2014). Forests play key roles in sequestering CO_2; however, globally land management activities and land-use change through deforestation, and degradation weakens their strength, resulting in an emission of 1.2 Pg C yr^{-1} (Joshua et al., 2017; Van der Werf et al., 2009). Converting forestland to other land uses is a leading anthropogenic factor that potentially affects the forest carbon stock and fluxes from regional to global scales (Caspersen et al., 2000; Pan et al., 2011; Zhou et al., 2013). Land use changes associated with deforestation and forest degradation are major contributors to the ongoing climate change, (Houghton, 2003) emitting CO_2 and other greenhouse gases (Baccini et al., 2012a) and is a critical issue among the scientific community (Sharma and Rai, 2007; Thompson et al., 2011). Around the globe, forests conversion upon deforestation released 156 Pg C to the atmosphere between 1850 and 2005 (Houghton, 2003). Deforestation is the second largest source, accounting for 12% to 15% of total global greenhouse gases emission (Chaplin-Kramer et al., 2015; Le Quere et al., 2009).

Deforestation not only transfer carbon to the atmosphere but also destroy the controlling mechanism of plants for CO_2 capture (Rokityanskiy et al., 2007). Forests acts as a source and sink of carbon, the emission removal potential of the forests can either be increased through conservative policies or can be reduced due to disturbance (Kishwan et al., 2012; Pandey, 2011). The regional pattern and magnitude of carbon sinks and source are uncertain due to variable driving mechanisms (Houghton, 2010). Deforestation and forest degradation have both natural causes, e.g., storms, flood, fire, and disease, and human causes, e.g., agriculture, illegal cutting, and infrastructure development. Population growth, poverty, government policies, technological development, changes in cultural attitude towards the forest, and stronger incentives for forest conservation are the underlying and controlling forces for deforestation and forest degradation (Keenan et al., 2015). Understanding drivers of deforestation and forest degradation and their monitoring is essential for making policies and measures for cutting emissions from deforestation, forest degradation

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and enhancing forest carbon through sustainable forest management approaches (Hosonuma et al., 2012). Concerns regarding climate changes have forced the international community to monitor terrestrial carbon, which is the key component of national scale reporting. The Intergovernmental Panel on Climate Change (IPCC), guidelines for national greenhouse gases measurement strictly require monitoring carbon pool by land use changes and forestry and wood removals (Böttcher et al., 2008). Similarly, the United Nations collaborative program on reducing emissions from deforestation and forest degradation on combating climate change also requires the regional and periodic estimation of carbon in the forest ecosystem (Le Quere et al., 2009).

The conversion of forest to a specific land by deforestation and reduction in cover by degradation are the dominant identifier of carbon losses in a country and regions within a country (Baccini et al., 2012b). Pakistan is a member state of the United Nations Framework Convention on Climate Change (UNFCC) and also part of the IPCC. As a member state, the country is required to document the greenhouse gases emitted by sources and removal by sink using the IPCC-proposed guidelines. Five percent country's geographical area is under forest, mostly located in the Hindukush Himalaya ranges that are facing drastic changes in land cover from deforestation and forest degradation. Studies in Pakistan have primarily focused on the carbon budgeting in various forest types, such as (Nizami, 2012) subtropical forests, (Adnan et al., 2014) temperate regions, and (Saeed et al., 2016) planted forests. In Pakistan, several studies have only described carbon storage under certain land uses (Ahmad and Nizami, 2015). A number of the studies tended to focus on the trend and pattern of land use change, the rate of deforestation, forest degradation, and wood requirements (Hassan et al., 2016; Qamer et al., 2016; Tahir et al., 2010). Similarly, in Pakistan at the national level, (FAO, 2015) estimates the carbon stock in the living tree biomass (174 million tonnes), the trend in forest area (-2.1% yr^{-1}), and trend in biomass carbon (-2.5% yr^{-1}) between 1990 and 2015. More recently, the annual forest lost (3980 ha) due to deforestation between 2001 and 2016 has been reported at national and sub-net levels (Hansen et al., 2013).

While national and sub net reporting would be essential, for monitoring deforestation, forest degradation, and carbon stocks, these available reports may not be sufficiently capture the real picture of ongoing deforestation, forest degradation, and carbon stocks at the regional and local level. Furthermore, wood harvest data are also required in calculating carbon dynamics and to illustrate the carbon flow and accumulation rate in a forest ecosystem. Therefore, a regional baseline study is needed to investigate the rate of deforestation, forest degradation, and wood harvest, and their integrated carbon emissions. Thus, we estimated the rate of deforestation, forest degradation, and wood harvest and analyzed their integrated impact on carbon emission in temperate regions of Hindukush Himalaya. Most of the forests in the Hindukush regions are legally declared as "protected forests" which are borrowed by multiple rights and concessions such as livestock grazing, fodder, and fuelwood collection, and getting timber for domestic constructions. In these forests, previously no proper estimates were made regarding the growing stock measurement, average annual firewood and timber requirements (for local peoples), and annual timber available for commercial exploitation. However, estimates of wood harvest for local peoples and commercial exploration have been worked out since 1994 (Saddozi, 1995). In this study, we used remotely sensed data to identify land uses and land use change patterns combine with carbon inventory and harvest data from 1994 to 2016. We compared carbon stocks in different land uses and showed how the carbon value varied with land uses and land use changes. We quantified the rate of deforestation, forest degradation, wood harvest and their associated carbon losses. We furthermore correlated annual wood harvest and associated carbon loss with population growth. We showed that carbon losses with wood harvest were the function of population growth, while multi-faceted drivers affect carbon losses related to deforestation and forest degradation.

2. Materials and methods

2.1. Study area

The study was performed in Kumrat, as the representative of the Hindukush Himalaya range of Khyber Pakhtunkhwa, Pakistan, lying between 35° 28′ 30″ to 35° 39′ 0″ N and 72°10′ 30″ to 72° 21′ 0″ E. Topographically, the area is characterized by hilly landscapes with elevation ranges from 2000 m to 6000 m. The rocks are mostly igneous and Meta-sedimentary. The area has a temperate type climate. The area receives mean annual rainfall from 1000 to 1200 mm. Temperatures varied with a minimum of 0.3 °C in December and a maximum of 25 °C in June (Ahmad and Nizami, 2015). The soil has loam or sandy loam textures, porous and rich in humus. The average soil organic matter varied between 1.20–4.58% and the average organic carbon varied between 0.72–2.65% (Ahmad and Nizami, 2015; Ahmed et al., 2011). In general, the area is dominated by coniferous forest, with small and degraded fragments of Oak forest. In addition to forests, other major land use types include agriculture lands, rangelands, water bodies, and snow and barren lands. Barren lands are mostly located above 4000 m and most often covered with snow. Glaciers in the area occur above 5000 m elevation. Based on ground verifications, forests of the area were broadly classified into Deodar forest (CD), Kail forest (PW), Fir forest (AP) and Mix coniferous forest (MC). The major tree species of the area includes *Cedrus deodar*, *Pinus wallichiana*, *Abies pindrow*, *Picea smithiana*, *Taxus bacata*, *Quercus baloot*, *Betula utilis*, *Platanus orientalis*, *Juglans regia*, *Aesculus indica, Poplus ciliata* and *Acer caesium*.

2.2. Land uses and land use change detection

The land uses and land use changes were generated from Landsat images of 1994 and 2016 from

United States Geological Survey (USGS) (http://glovis.usgs.gov). The selections of images were made on basis of quality and cloud-free images. The multispectral Landsat 5 T M imagery 1994 and Landsat 8 Oil imagery 2016, with 30 m resolution in the scale of 1:50,000, in combination with the country topographic map were used. The map was first scanned and processed with the processing software. Preprocessing of the image is critical before the classification and change detection for establishing a relationship between acquired data and biophysical process (Abd El-Kawy et al., 2011). The geometric correction was performed from a topographic sheet of the area as a reference as well as from the GPS by taking 126 ground control points (which were taken during the field inventory) using ENVI 5.1. The radiometric and atmospheric corrections were performed using FLAASH (Fast Line-of-Sight Atmospheric Analysis of Hypercubes) and radiometric calibration tools available in ENVI 5.1, respectively.

All the satellite data were examined and per-pixel signatures were assigned, thereby classifying the study area into different classes of dense forest, open forest and range land, agricultural land, barren land, water bodies, and snow. Subsequently, different colors were assigned to the classes to differentiate them and maximum likelihood algorithm in supervised classification was performed. Post classification smoothing was performed to improve the quality, of classification, and to classify the unclassed pixels. The accuracy of the classified images were assessed by Confusion matrix ground truth image. The accuracy was assessed by using 50 ground control points in each land use (GCPs) based on ground and visual interpretation. Kappa statistics was also applied to check the accuracy of the classified images. For change detection, the accuracy of the individual class was assessed. Post-classification change detection techniques were also performed in ENVI 5.1 and new maps of change from-to were prepared. The land use data generated through satellite imagery was classified into the dense forest (DF), sparse vegetation (open forest (OF) and rangeland (RL) agriculture land (AL),