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Soil Organic Carbon Stocks Assessment in Uttarakhand State using Remote Sensing and GIS Technique

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ABSTRACT

Soil organic carbon (SOC) content is key component of the global carbon (C) cycle which is highly variable with respect to space and time. The main objective of this study was to provide an assessment of soil organic carbon (SOC) stock variability for Uttarakhand state. The other objective of this study was to evaluate the performance of different pedotransfer functions for reliable assessment of bulk density. Soil Resource Mapping for Uttarakhand state was conducted on 1:50,000 scale with the help of Satellite imagery (LISS III) along with exhaustive ground truthing through soil surveys. Stratified sampling was carried out based on remotely sensed satellite data for different slope, physiography and land-use/cover. The physico-chemical properties of selected samples for agriculture and forest land use were utilized for analyzing the performance of six pedotransfer functions for assessment of bulk density. The SOC stocks were estimated on the basis of soil organic matter content for top 20 cm layer and bulk density estimated from best performing pedotransfer functions models. The SOC stock class of 51-100 tonnes C ha^{-1} was dominated by covering 42.00% of state area followed by 26-50 tonnes C ha^{-1} class covering 23.74% area. Similarly, about 7.91% and 3.24 % area of state are covered under 11-25 tonnes C ha^{-1} and 101-160 tonnes C ha^{-1} classes, respectively. Remaining 22.44 % of state not forms part of study were mapped under settlement, snowbound area, drainages/rivers, reservoirs etc. The difference in performance of pedotransfer functions under different land use system implies the necessity of evaluation of pedotransfer functions before their implementation. Significantly greater SOC stocks were observed in forest and grassland/open-scrub land use and such differences can be attributed to the higher tree/shrub density, shrub/herb biomass and forest litter in the forest areas as compared to agriculture land use.

Introduction

Greenhouse gases (GHGs) emission from anthropogenic activities is considered to be most significant driver of observed climate change since the mid-20th century. In annual report for the year 2017, National Centers for Environmental Information (NCEI) ref reported that global annual land surface temperature was 1.31°C above the 20th century average and also the third highest in the 138-year record, behind 2016 (warmest) and 2015 (second warmest). The global oceans also had their third warmest year since global records began in 1880 at 0.67°C (1.21°F) above the 20th century average (Global Climate Report, 2017)

The resulting variability of climate poses threat to the environment and the quality of human life over the world. It is for this reason; the parties to the United Nations Frame Work Convention on Climate Change (UNFCCC) have undertaken a comprehensive exercise to address the issues of climate change adaptation and mitigation. For such an undertaking, the assessment and management of natural carbon sources and sinks has proven to be most vital and practical approach to regulate the level of GHGs in the atmosphere.

Systems involving vegetation act as carbon sinks due to their ability to sequester from atmospheric carbon to deep layers of soil profile. Atmospheric carbon can be sequestered in long-lived carbon pools of plant biomass both above and below ground or recalcitrant organic and inorganic carbon in soils and deeper subsurface environments.

Soil organic carbon (SOC) is the carbon held within soil organic constituents (i.e., products produced as dead plants and animals decompose and the soil microbial biomass). The SOC stock to 1m depth ranges from 30 tons C /ha in arid climates to 800 tons/ha in organic soils in cold regions, and a predominant range of 50 to 150 tons C /ha (Lal, 2004). Soils are considered as the largest carbon reservoirs of the terrestrial carbon cycle storing 2344 Pg (1 Pg = 1015 g) of carbon (C) up to 3 m depth which is more than twice that in vegetation (359 Pg) and atmosphere (760 Pg) combined. The size of the soil organic matter pool is determined by the rate of input of fresh organic matter, the proportion of humified carbon and the rate of efflux of carbon (Lal, 2001). There is established link between soil quality and soil organic carbon (SOC) concentration and atmospheric carbon.

With this work, we aim to make an assessment of SOC stock in Uttarakhand state of India as a unit under different soils and landuse systems (with its extent on surface layer i.e. 25 cm). Information on carbon status could aid in estimating carbon sequestration potential for this important but fragile ecosystem of Uttarakhand state, India. The information generated in this study will be useful for policy-makers and environmentalists for undertaking appropriate conservation plans.

Materials and Methods

Study area

Uttarakhand state is a part of the north-western Himalayas bounded by Nepal in the East and Himachal Pradesh in the West while the northern boundary goes up to Tibet/China, whereas southern boundary extends into Indo-Gangetic plains. The state lies between 28^0 43' and 31^0 27’ N Latitude and 77^0 34’ and 81^0 02’ E Longitude with total geographical area of 53,48,379 ha, out of which approximately 84.7% is mountainous. About 20.03% of total geographical area is under snow cover/glaciers and steep slopes. The major North Indian rivers – the Ganga and the Yamuna, originate from this region. Uttarakhand state covers 13 districts within two revenue divisions (Figure 1). Out of total geographical area, 41,48,338 ha area was covered under this study while remaining 12,00,040 ha area was covered under miscellaneous landuse i.e. habitation, rockout crop, snow cover and waterbodies.

The climate of Uttarakhand state can be characterized as subtropical. Within the same catchment subtropical even tropical climate is often observed at the lower end of the watershed i.e. in valleys, while temperate climate prevails in the upper reaches of the stream. The mean annual rainfall varies from 1100 to1600 mm with intensity ranging from drizzling to torrential rain. The rainfall is heavy and well distributed in from June to September the wet season accurse during these months, the rainfall is moderate during May and October and the rainfall is low during November to February.

Soil resource mapping survey

The study was conducted during 2010-12 in the state of Uttarakhand by Soil and Land Use Survey of India (SLUSI) using guidelines developed for Soil Resource Mapping. The area of interest was large, having high altitudinal variation and other biophysical factors such as climate, slope and topography that influence soil type and biomass accumulation (and therefore Soil mapping and C stocks assessed in stratified fashion), stratification was carried on the basis of altitude zones and random selection of sampling points on differences in slope, physiography and landuse/cover in order to reduce uncertainty. Development of data on 1:50,000 scale to the extent of the area of interest was done to design of an effective sampling procedure to depict extent of area.

Stratified sampling using remotely sensed LISS III (Spatial resolution 23.5 m) satellite data based on differences in slope, physiography, altitude and land-use/cover collected randomly along the road side taking in to account remoteness/inaccessibility of region. Carbon accounting making use of stratified random sampling has the benefits when compared to a random sampling approach. In this case, stratification refers to the division of a heterogeneous landscape into distinct strata based on the carbon stock in the vegetation. The benefits of this method are:

a. If the strata are well defined and internally homogeneous (relative to all areas of equal altitude zones), the number of samples required to achieve a specified accuracy of the mean is considerably smaller than with random sampling.

b. The method is more robust if the overall distribution does not follow a normal random distribution, but still assumes deviations from such a distribution within each stratum are manageable in carbon accounting, maps derived from remote sensing (or direct attributes at the unit or pixel scale) form the strata containing range of slopes, land use/ cover types. The LISS III data generally have higher precision on low carbon density landscapes and variations within high carbon density categories.

Preparation and processing of samples

In the laboratory, samples for C analysis were dried in a solar oven and then sieved first through 20 mm mesh and then through 2 mm mesh. The plant roots and other visible fractions were removed and a fraction of each specimen was ground and reduced to particles with maximum diameter of 50 microns before automatic chemical analysis. Samples for determination of bulk density were placed to dry in KR box in an electric oven at 105 °C for approximately 72 hours.

Analysis of pH, total carbon content and particle size distribution

Soil pH of the samples was determined in a soil water suspension (1:2.5) by pH meter using a glass electrode. Organic Carbon was estimated by Walkley and Black method (Jackson, 1973).

Particle size distribution (mechanical analysis) of soil sample was determined by Bouyoucos Hydrometer method (Bouyoucos, 1962).

Estimation of bulk density

For agriculture and forest landuse system, selected samples were analyzed in laboratory for estimation of bulk density as per standard Keen Raczkowski box technique (Black, 1965).

The various cases reported in literature indicates that the bulk density is closely associated with soil physical and chemical properties and can be estimated using pedotransfer functions but the performances of pedotransfer functions varies when subjected to different soils and landuse systems. The majority of these studies support the recommendation to apply these functions with care and evaluate the best function for each soil conditions before further applications (Abdelbaki, 2016; Xu *et al.*, 2015 and Kaur *et al.*, 2002).

Many researchers have observed that the soil texture is the most significantly related soil property which is related to bulk density of soil due to which sand and clay are the most essential parameter used in most of the pedotransfer functions models (Kumar *et al.*, 2009). The soil organic carbon is considered to be second after soil texture in governing the soil bulk density and is reported to have a significant but negative correlation with bulk density of soil (Chaudhari *et al.*, 2013; Sakin, 2012; Sakin *et al.*, 2011; Leifeld *et al.*, 2005 and Morisada *et al.*, 2004). Therefore, keeping these facts in mid, the physico-chemical characteristics of 130 samples analyzed in laboratory for agriculture and forest land use were used for estimation of bulk density through six different models based on pedotransfer functions selected form literature and the calculated bulk density of these three models were plotted in against the values of observed bulk density and plotted graphs were utilized to work out coefficient of determination (R^2 value), thereby validating the models as per mentioned in literature (Abdelbaki, 2016; Bernoux *et al.*, 1998; Tomasella and Hodnett, 1998 and Benites *et al.*, 2007).

The equations used to estimate the bulk density values from the aforesaid models are as under:

Model 1: Bulk Density (kg/dm^3) = 1.419 - 0.0037 × clay (%) - 0.061 × carbon (%)

Model 2: Bulk Density (kg/dm^3) = 1.5688 - 0.0005 × clay (g/kg) - 0.009 × carbon (g/kg)

Model 3: Bulk Density (kg/dm^3) = 1.578 - 0.054 × carbon (%) - 0.006 × silt (%) - 0.004 × clay (%)

Model 4: Bulk Density (kg/dm^3) = 0.69794 + 0.750636 Exp [-0.230355 x OC (%)] + [0.0008687 x sand (%)] + [0.0005164 x clay (%)]

Model 5: Bulk Density (kg/dm^3) = 1.66 - 0.308 (OC)$^{0.5}$

Model 6: Bulk Density (kg/dm^3) = 0.167 x 1.526/ {1.526 x OM (%) + 0.159 [1-OM (%)]/100)}

Calculation of SOC stock

SOC stocks were calculated for each mapping unit using analytical data of associated soil series in mapping units using following formula:

SOC stock (t C ha^{-1})= depth (m) x bulk density (Mg cm^{-3}) x OC (g kg^{-1})

The observed SOC stocks were categorized in five groups (0 - 10, 11 - 25, 26 - 50, 51 - 100 and 101 -160 t C ha^{-1}) for the state. The present study has been aimed at SOC stock mapping for assessment of SOC stocks under different land uses of Uttarakhand state. The soil layer developed in Soil Resource mapping survey developed using remote sensing (RS) technique in GIS software Arc-GIS 10.3 was used as base for preparing SOC stock map.

Results and Discussion

Comparison of models for bulk density determination

The plotted graphs of estimated bulk density against observed bulk density observed best R^2 value for agriculture (0.811) for pedotransfer function "model 2" equation whereas "model 1" observed best R^2 value (0.702) for forest land use (Figure 2 and 3). Therefore "model 2" was selected for estimation of bulk density in agriculture landuse while "model 1" was used for estimation of bulk density in forest, plantation and open scrub land uses. The inconsistency in performance of pedotransfer function models for bulk density models for different land use systems. These results supports the findings of various studies which supports the evaluation of these pedotransfer function models due to their difference in performance under different land conditions (Nanko *et al.*, 2014; Han *et al.*, 2012; Jalabert *et al.*, 2010; Martin *et al.*, 2009)

SOC stock in Uttarakhand state

Among different classes of SOC stock, the maximum area of 22,46,367 ha was covered under SOC stock class of 51 - 100 t C ha^{-1} followed by SOC stock classes of 26 - 50 t C ha^{-1} (12,69,597 ha), 11 - 25 t C ha^{-1} (4,22,794 ha), 101 - 160 t C ha^{-1} (1,73,488 ha) and 0 - 10 t C ha^{-1} (36,092 ha), respectively (Table 1 and Figure 4).

SOC stock in different districts

The SOC stock class of 51 - 100 t C ha^{-1} was the dominant class in the eight out of thirteen districts of Uttarakhand state (except Bageshwar, Champawat, Haridwar, Nainital and Udham Singh Nagar districts) covering an area of 42.00% and 30.60% area out of total geographical area and total surveyed area, respectively (Table 1 and Figure 4). The districts covering the mountainous area of state observed higher SOC stocks due to having majority of area under forests and open scrub which have higher SOC content as compared to agriculture soils.

SOC stock under different landuse systems

The landuse systems of forest and grassland/open-scrub observed to have majority of area having SOC stock more than 51 t C ha^{-1} (72.65% of forest area and 77.70% area under grassland/open-scrub) as compared to agriculture where 81.44% area was recorded to have less than 50 t C ha^{-1} SOC stock (Table 2). These results are in agreement with literature that the forest and grasslands have higher potential of accumulating and conserving SOC as compared to agriculture as the change in landuse from forest and grassland to agriculture is accompanied by loss in SOC (Kassa *et al.*, 2017; Martín *et al.*, 2016; Poeplau and Don, 2013; Kuimi *et al.*, 2016).

The occurrence of higher SOC content in both forest and grassland/open-scrub can be attributed to the litter fall addition from trees and shrubs to the surface soil (Yimer *et al.*, 2015; Worku *et al.*, 2014 and Nsabimana *et al.*, 2008) Furthermore, the forest and grassland/open-scrub possess a higher organic carbon; through dead fine tree and shrub roots and the mycorrhizal fungi contribution of organic matter (Yimer *et al.*, 2007 and Lemma *et al.*, 2006). Whereas, the low carbon stocks were observed in agriculture land-use as soils in these area are subjected to continuous loss of SOC due to frequent soil disturbance, crop uptake, leaching and surface erosion losses, and inadequate land management.

Table.1 District wise area distribution of SOC stocks in Uttarakhand state

Districts	**Area (ha)**									
	SOC stock (t C ha^{-1})					**Miscellaneous**				
	0 - 10	***11 - 25***	***26 - 50***	***51 - 100***	***101 -160***	***Habitation***	***Rockout Crop***	***Snow Cover***	***Waterbodies***	**Total area**
Almora	783	5003	108225	191482	704	1184	-	-	3065	310446
Bageshwar	-	36554	78952	73923	9807	65	-	27338	738	227377
Chamoli	-	11640	75603	321865	49652	34	173	314754	2893	776613
Champawat	6388	17283	85910	59250	1758	183	217	-	6978	177967
Dehradun	-	-	59119	222780	1041	9960	-	-	11973	304872
Haridwar	4556	161560	33004	15553	-	6981	-	-	15424	237078
Nainital	9998	78329	170915	135924	-	876	-	-	16065	412106
Pauri Garhwal	14367	54095	215584	228845	867	53	-	-	14719	528530
Pithoragarh	-	10435	40976	378684	34795	674	950	254047	3366	723927
Rudraprayag	-	737	28940	134810	2813	19	-	31011	1210	199541
Tehri Garhwal	-	3156	125911	198875	33929	239	-	24126	4020	390258
Udham Singh Nagar	-	38181	187283	5841	-	5310	-	-	17571	254188
Uttarkashi	-	5820	59176	278533	38122	139	-	420265	3421	805477
Total Area	**4148338**					**1200040**				**5348379**

Table.2 Distribution of SOC stocks with respect to landuse in Uttarakhand state

Landuse	SOC stock (t C ha^{-1})					Total Area (ha)
	0 - 10	*11 - 25*	*26 - 50*	*51 - 100*	*101 -160*	
Agriculture	11203	208797	690352	206511	1041	**1117904**
Forest	24889	202786	413894	1541592	162687	**2345847**
Grassland/Open-scrub	-	4158	141117	496868	9761	**651903**
Plantation	-	7053	24235	1395	-	**32683**
Habitation						**25717**
Rockout Crop						**1340**
Snow Cover						**1071541**
Waterbodies						**101443**
Total Area (ha)	**36092**	**422794**	**1269597**	**2246367**	**173488**	**5348379**

Fig.1 Location map of Uttarakhand state

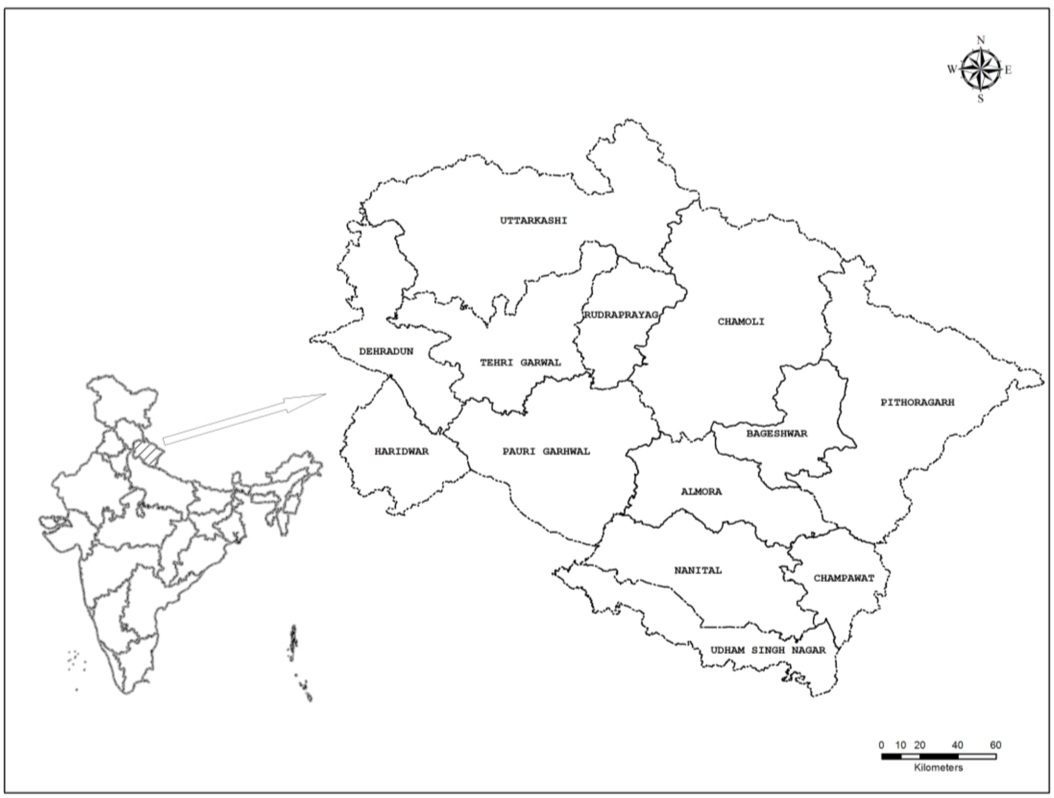


Fig.2 Validation of models for predicting bulk density of agriculture land use

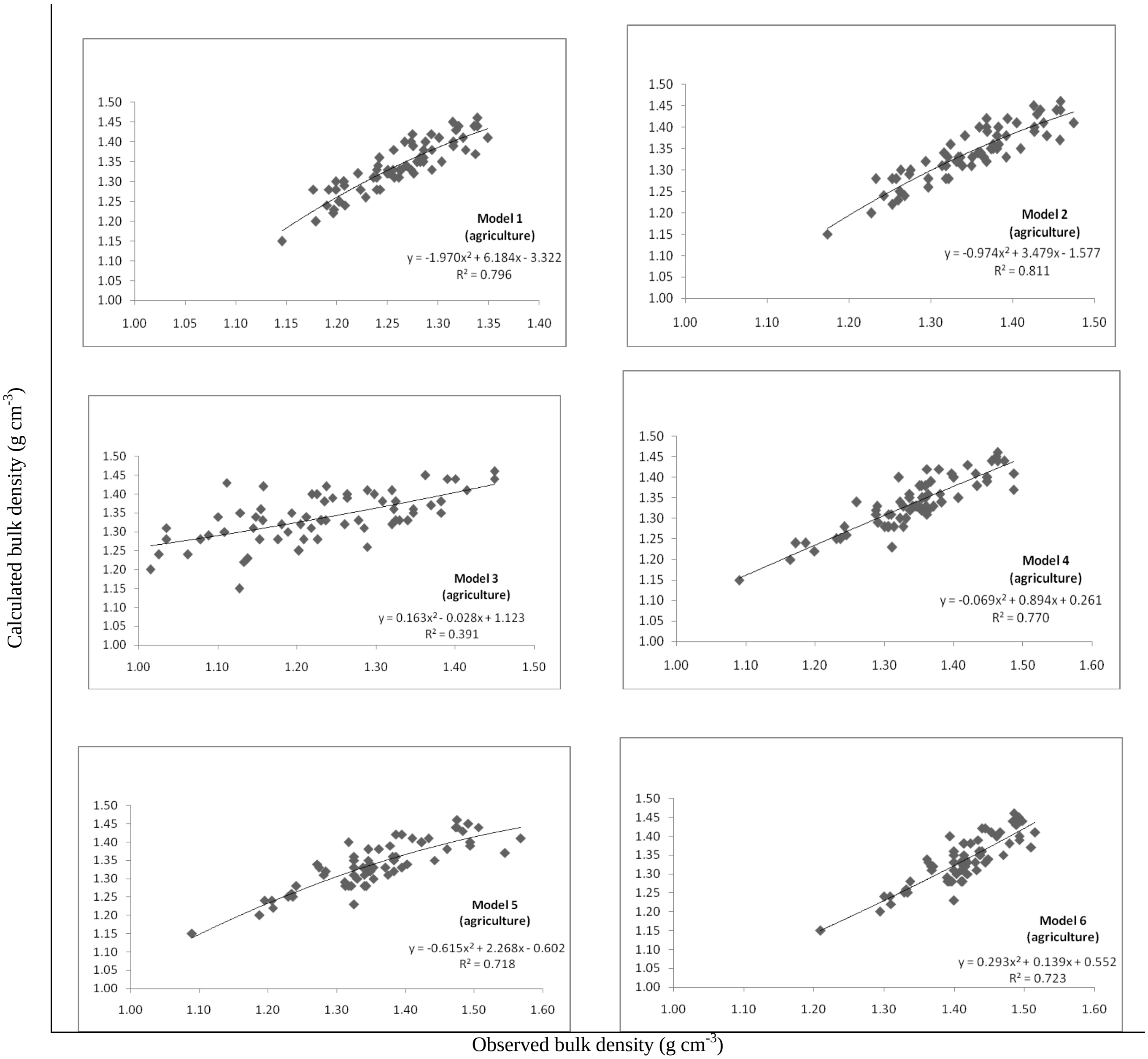


Fig.3 Validation of models for predicting bulk density of forest landuse

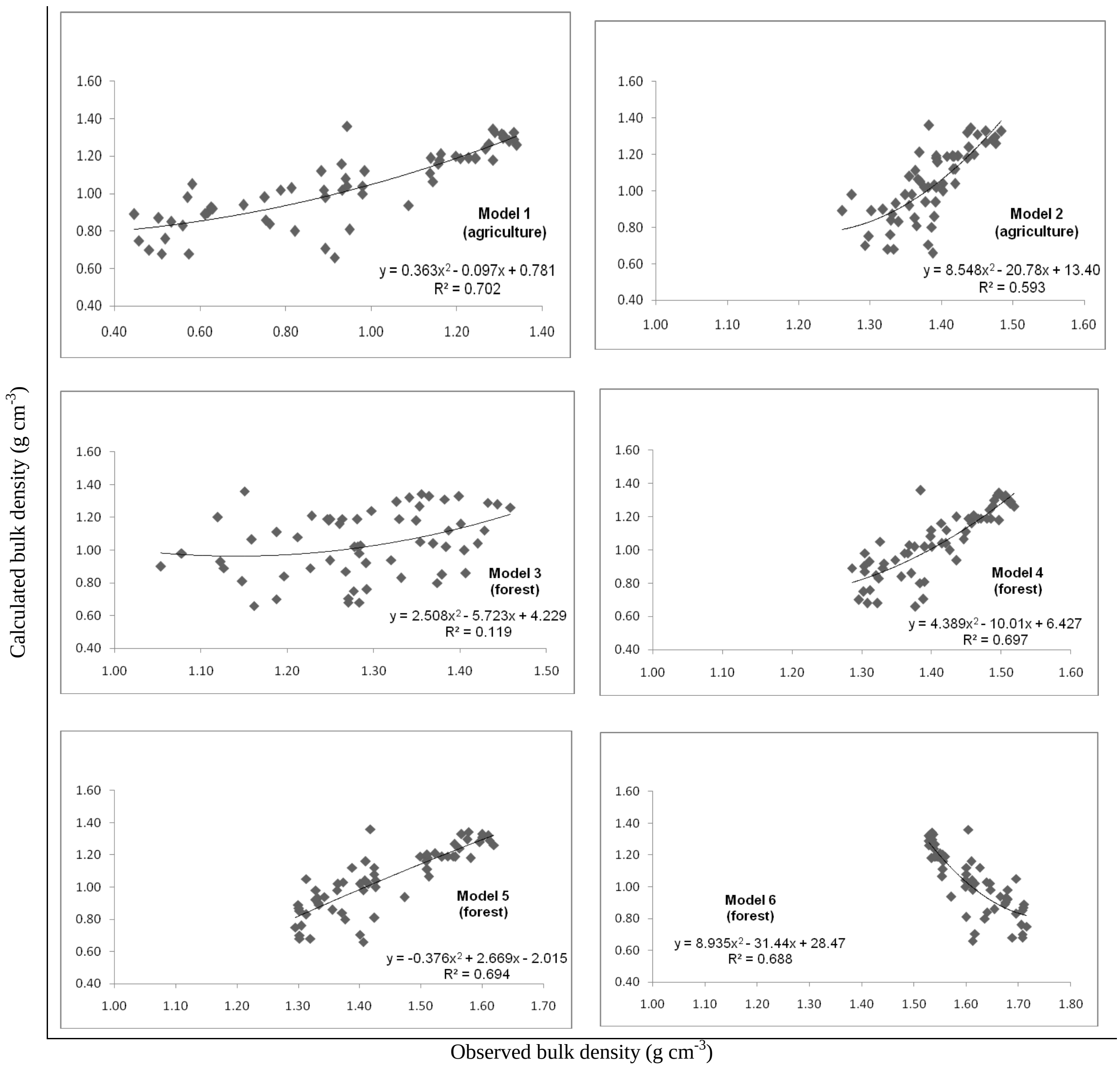
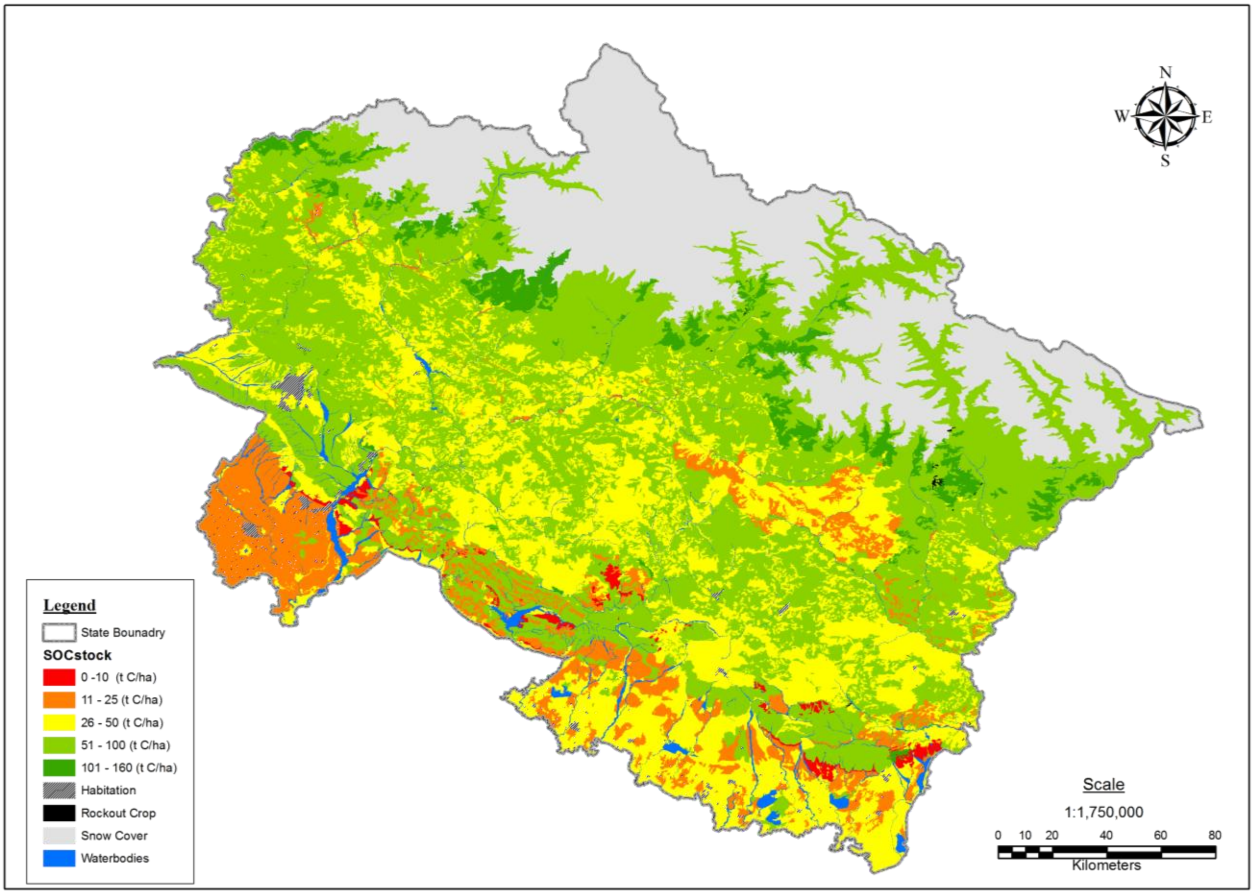


Fig.4 Spatial distribution of SOC stock classes in Uttarakhand state



The crop residue removal and grazing after the harvest and are found in concordance with the findings of Don *et al.,* (2011) and Lemenih and Itanna (2004).

The majority of the forest and grassland/open-scrub lies with in the mountainous region of the state and are generally subjected to higher risk of soil erosion due to higher degree of slopes. However, these areas are also reported to have higher risk of soil loss through erosion due to higher degree of land slope and high rainfall and are subjected to frequent occurrences of landslides every year (Mahapatra *et al.,* 2018).

In conclusion, present study demonstrated the application of random sampling for the estimation of bulk density for estimating SOC stocks across landscapes in mountainous areas. The method applied is simple and allows for reliable and robust measurements of soil carbon stocks in different soil types and under different land cover and land-use systems. Furthermore, this study also confirms that the performance of pedotransfer function in assessment of bulk density varies with the type of land use system.

The land use wise distribution revealed that the forests and grasslands are the major contributor toward the state SOC stock as 72.65% of forest area and 77.70% area under grassland /open-scrub were found to have SOC stock above 50 t C ha^{-1}, while majority of these area lies in mountainous region of state and subjected to high risk of soil erosion. Therefore, such area requires special attention for management and conservation of these SOC stocks.

This study has generated the SOC stock database and its spatial distribution in the state which can be taken as base line information for future monitoring of SOC stocks.

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