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Digital mapping of soil organic and inorganic carbon status in India

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ABSTRACT

Reliable mapping of soil organic carbon (SOC) and Soil Inorganic Carbon (SIC) densities and estimates of their pool size are important from global warming perspective to understand the sequestration potential and losses. In this study, first spatially explicit mapping of SOC and SIC at 250 m resolution and an estimate of their pool size in India was undertaken using a large number of remote sensing derived data layers and data mining approach. The SOC and SIC densities up to 100 cm depth or paralithic contact (whichever is shallower) were estimated for 1198 soil samples located across India using a stratified random sampling that integrated land use, soil, topography and agro-ecological regions.

Using Random forests (RF) based spatial prediction procedure with climatic, land cover, rock type, soil type, multi-year NDVI, irrigation status as independent input variables, models for predicting carbon density at 250 m spatial resolution were developed. For modelling with RF algorithm, about 898 soil profile observations (75% observations) were used, while the rest of 300 (25% of total observations) were used for validation. It was observed that the data distribution of sample points don't have significant influence on RF model predictions. The relationship between observed and predicted values was characterized by Mean Squared Deviation (MSD) and Root Mean Squared Error (RMSE) parameters. The SOC, SIC and total soil carbon pool size of India has been estimated at 22.72 ± 0.93 Pg,12.83 ± 1.35 Pg and 35.55 ± 1.87 Pg, respectively, which are comparable to previous studies while providing first spatially explicit 250 m map of their distribution. The spatial distribution indicates that majority of the carbon stock resides in the northern part of India. The soil carbon stock of eastern India has contribution from organic carbon, while the western portion has contribution mainly from inorganic carbon.

1. Introduction

Soil organic and inorganic carbon constitute the largest terrestrial carbon pool, storing more than thrice the quantity of carbon in vegetation or double the quantity of carbon in atmosphere (Batjes and Sombroek, 1997; Schlesinger, 1997; Eswaran et al., 2000).

Due to concerns on global warming and its subsequent effects on climate variability, several researchers across globe investigated the quantity, type and distribution of soil carbon. Though the global estimates gave an idea of pool size, the precise local estimates and the factors affecting the soil carbon dynamics are very important from management perspective. Being the largest contributor to global carbon pool, even a minor change in soil carbon stocks could result in significant changes in atmospheric CO_2 concentration (Davidson and Janssens, 2006). Hence, both SIC and SOC pools play an important role in understanding the future soil carbon dynamics and its management.

1.1. Soil organic carbon

Several important external factors contribute to variation in SOC levels of soils. They include climate, hydrology, parent material, inherent soil fertility, biological activity, vegetation patterns and land use (Jenny, 1941). The most important renewable source to enrich the soil with organic carbon is through phytomass accumulation. However, expanding crop lands to meet the global food requirement comes with a cost of reduced carbon stocks (West et al., 2010; Saha et al., 2012).

In general, the processes operating on organic matter cycle appears to be similar in dry or hot regions and temperate zones where carbon

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levels are generally higher (Batjes and Sombroek, 1997; Syers, 1997). The accumulation of carbon is favoured by low temperatures, acidic environment and anaerobic conditions, which do not promote decomposition of organic matter. Inventory of soil organic carbon storage and its spatial distribution as well as temporal dynamics is very important to understand the carbon cycle and climate change as well as developing future land-use policies. According to Lal et al. (1998), an increase in SOC content by 0.01% can substantially reduce the adverse consequences of annual increase in atmospheric carbon dioxide concentration.

1.2. Soil inorganic carbon

The SIC pool can be classified as lithogenic inorganic C (LIC) and pedogenic inorganic C (PIC). In arid and semiarid regions, which cover as much as one third of the Earth's surface, SIC pools and their dynamics are important as the rate of accumulation of SIC is generally higher than in other biomes (Lal, 2008). Out of the two SIC pools, PIC pool plays an important role in the global C cycle. To date, studies on SIC storage and dynamics have primarily focused on local or regional assessments (Monger and Matrinez-Rios, 2000; Rasmussen, 2006; Singh et al., 2007). SIC pool estimates at a national or global scale have been poorly documented in comparison to estimates of SOC pools (Lal et al., 1998; Guo et al., 2006).

Research studies have also shown the occurrence of significant changes in SIC pools of different soil types linked to climatic variation (Adams and Post, 1999; Landi et al., 2003), land use (Mikhailova and Post, 2006; Papiernik et al., 2007; Sartori et al., 2007), and atmospheric nutrient deposition (Goddard et al., 2007).

1.3. Pool estimation

To compute spatially explicit maps of soil carbon density, various computational approaches were attempted like point data interpolation (Agboadoh, 2011), multiple regressions, regression trees (Martin et al., 2011), artificial neural networks (Alvarez et al., 2011) and landscape modelling or digital soil mapping (Thompson et al., 2006; Minasny et al., 2013). The spatial interpolation approaches like Inverse Distance Weighted (IDW) interpolation, kriging, conditional kriging are statistical and do not use the controlling parameters those govern the spatial distribution of dependent variable. Data mining techniques like Random forest (RF) and Artificial Neural Networks (ANN) can be used for modelling the relationship between dependent as well as independent variables, but will not consider the neighbourhood while building the model.

Random forest (RF) data mining technique, a regression tree based technique, suitable for modelling the relationship between dependent and independent variables with capability to handle categorical and numeric independent variables was considered. Recently Sreenivas et al. (2014) have used Random forest (RF) data mining with a large number of remote sensing derived metrics for mapping the SOC density for states of Andhra Pradesh and Karnataka (India) at spatial resolution of 1 km.

Globally, the estimated pool size of SOC in the 100 cm depth is 1200 to 1600 Pg (Lal, 2004; Batjes, 1996; Xu et al., 2013) while the size of SIC has been estimated as 695 to 1738 Pg (Batjes, 1996; Eswaran et al., 1993; Sombroek et al., 1993) for similar depth. While SOC stocks are dominantly stored in humid temperate regions, the major portion of SIC stocks are stored in arid and semi-arid regions (Díaz-Hernández et al., 2003).

The estimated SOC pool size of India by various authors varied between 21 and 27 Pg (Dadhwal and Nayak, 1993; Bhattacharyya et al., 2000). In India, SOC density for different forest types as well as SOC pool for forest ecosystem have also been estimated as 4.13 Pg (Chhabra et al., 2003) and 5.25 Pg (Velmurugan et al., 2014) for top 50 cm soil depth. Indian SIC pool has been estimated at 22.46 Pg by Bhattacharyya et al. (2008).

In addition, several regional site specific studies in arid and semi-arid regions have brought out varied soil carbon densities in these regions. These estimates were made by using the soil samples collected over a long period as well as analysed under varied laboratory analytical procedures which may lead to inconsistencies in estimation. To reduce the amount of such inconsistencies that could arrive from laboratory methods, in the present study we have adopted a more consistent approach of field sampling carried out during 2010–2012 and soil samples analysis through a single analytical procedure and type of instrument. Globally, efforts are being made to standardize the analytical procedures and nomenclature for soil properties and procedures for spatial prediction with limited data (Arrouays et al., 2014) (http://www.globalsoilmap.net).

With high and very heterogeneous spatial distribution of carbon densities, reliable estimation of soil carbon pool is dependent on its accurate spatial assessment as well as adequate sampling of point densities with proper validation mechanism. The present study was taken up as a part of ISRO Geosphere–Biosphere Programme (IGBP) with an objective to establish spatially explicit soil organic and inorganic carbon density maps as well as to estimate the size of these pools using a remote sensing and data mining based spatial modelling approach. The approach of Sreenivas et al. (2014) is applied for both SOC and SIC with geospatial modelling approach at resolution of 250 m. In their previous research Sreenivas et al. (2014) demonstrated the applicability of RF modelling to spatially predict the top 30 cm SOC density only. In the current research, modelling has been attempted for entire soil profile (to a maximum depth of 100 cm) for both SOC and SIC densities. The current research, for the first time provides a spatially explicit distribution of SOC and SIC densities for the entire India. The enlarged scope of this spatial modelling approach will be to develop a predictive model for assessing the impact of climate and land use changes on carbon density and stocks.

2. Study area and materials

2.1. Study area

India, with a total geographical area (TGA) of 328.7 Mha, extending between 68.1°E to 97.5°E longitude and 6.6°N to 37.1°N latitude forms the study area. It has ample climate, lithological as well as land cover variations that has impacted in varied distribution of soil carbon content. The country has cold deserts in the North and hot desert in the North-West region (Rajasthan). The average annual rainfall of the country ranges between 13 cm to 1141 cm (Attri and Tyagi, 2010). About 43% of TGA of the country contributes to net sown area. Forests occupy 20.34% of geographical area of the country consisting of evergreen, semi-evergreen, deciduous forests of various cover densities. Besides, about 4% of tree cover is under tree grooves and plantations (NRSC, 2010). There is also a great variation in soil type with barren rocky to very shallow skeletal soils in the Jammu & Kashmir and Himachal Pradesh cold desert hilly region, desertic sands in the west, deep alluviums in northern alluvial belt, acidic soils with base-poor A horizon in the East. The central plateau has soils originated from varied rock types mainly from Basalts and Granite-Gneisses. Thus the entire country with varied climate, land cover and soil types offers a challenging environment to model any spatial assessment.

2.2. Materials

Keeping the considerations in view, the climate as represented by rainfall and temperature, vegetation influence as represented by land cover and cumulative NDVI were considered as inputs for modelling SOC densities besides soil type and irrigation status. The soil type and depth has influence on quantum of organic matter and inorganic C