International Journal of Plant & Soil Science

33(6): 54-77, 2021; Article no.IJPSS.67425
ISSN: 2320-7035

Spatial Pattern of Soil Carbon Density in Cultivated Land of Different Domains of Madhya Pradesh

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2021/v33i630444
Editor(s):
(1) Dr. Hon H. Ho, State University of New York, USA.
Reviewers:
(1) P.Senthilvalavan Annamalai, University,Annamalainagar, India.
(2) Kadri Karim, Regional Research Center on Oasis Agriculture, Tunisia.
Complete Peer review History: http://www.sdiarticle4.com/review-history/67425

Original Research Article

Received 04 February 2021
Accepted 08 April 2021
Published 27 April 2021

ABSTRACT

Present study was conducted in the Department of Soil Science JNKVV, Jabalpur during 2018-2020. GPS based 531 soil samples were collected from each domain *viz.,* Bhopal, Jabalpur, Vidisha and Hoshangabad of 10.1 Agro ecological sub region (AESR). The samples analyzed for soil organic carbon (SOC) and calcium carbonate ($CaCO_3$) then soil organic carbon density (SOCD), total organic carbon density (TOCD), soil inorganic carbon density (SICD) and total carbon density (TCD) in Mg C ha^{-1} were calculated. The results of SOCD, TOCD, SICD and TCD ranged from 4.73 to 25.12, 9.22 to 48.98, 1.00 to 21.29 and 11.08 to 68.80 Mg C ha^{-1} with mean value of 12.19, 23.78, 7.58 and 31.36 Mg C ha^{-1} in AESR 10.1 and Coefficient of variation (CV) 37.58, 37.58, 50.88 and 31.24 %. The overall trend in SOCD was Bhopal > Vidisha > Jabalpur > Hoshanagabad and SICD was Vidisha > Hoshanagabad > Jabalpur >Bhopal while TCD was in trend of Bhopal > Vidisha > Hoshangabad> Jabalpur.

Geo-statistical indicated that Ordinary Kriging used and all variogram were in isotropic form. In Bhopal domain, Gaussian model best fitted for of SOCD, TOCD, and TCD but spherical model for SICD. In Jabalpur domain, exponential domain best fitted for TCD and TOCD but for SICD, spherical model and for SOCD, Gaussian model is best fitted. In Vidisha domain, exponential

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model best fitted for all. In Hoshangabad domain, exponential model is best fitted for SOCD and TOCD and Gaussian and J-Bessel model best fitted for TCD and SIC, respectively. The nugget/ sill (N/S) ratio was <25% which exhibit strong SD only for SICD in Bhopal domain. The N/S ratio was found to be >25% but <75% which showed moderate SD, for SOCD, TOCD and TC, TOCD, SICD and TCD; SOCD, TOCD, SICD and TCD and SOCD, TOCD, SICD and TCD and SOCD, TOCD, SICD and TCD in Bhopal, Jabalpur, Vidisha and Hoshangabad domain, respectively. The correlation range (m) for SOCD, TOCD, SICD and TCD are 5448.413, 4809.535, 360.522, and 5113.050; 7201.044, 6601.044, 611.651, and 8438.711; 5734.559, 7334.398, 1323.773, and 7881.289 and 5418.684, 5433.206, 8887.656, and 1836.274 in Bhopal, Jabalpur, Vidisha and Hoshangabad domain, respectively. The carbon density was found in order of Jabalpur> Hoshangabad >Vidisha > Bhopal.

Keywords: Cultivated land; Geo-statistical tool; GIS; soil carbon density; spatial variability.

1. INTRODUCTION

Soils play an essential role in the global carbon (C) budget. Currently, the land sink (including soil and vegetation) absorbs about 30% of the C emitted to the atmosphere through the burning of fossil fuel and cement production (Le Quéré *et al.*2014). The exchange of carbon dioxide (CO_2) between the atmosphere and the biosphere is about 150 $X10^{15}$ g C yr^{-1}, so the biosphere is more likely to buffer the rise of carbon dioxide as a result of human activities [1].

Since the onset of agriculture around 8,000 years ago, soils have lost around 140–150 Gt C (~510–550 Gt CO_2; [2] through cultivation. It is known that best management practices can restore some at least some of this lost carbon [3], so it has been suggested that soil C sequestration could be a significant greenhouse gas (GHG) removal strategy [4]. According to the IPCC agricultural soils have the potential of sequestering up to 1.2 billion tonnes of carbon per year. However, it has been estimated that already about 50% of agricultural soils have been degraded globally, a situation that creates an opportunity for sequestering atmospheric carbon in the soil for a long period of time IPCC, [5]. The potential of sequestering carbon in agricultural land is huge as over one third of the worlds arable land is in agriculture. Agricultural land could sequester at least 10% of the current annual emissions of 8–10 Gt/year [6].

Soils constitute the largest active terrestrial C pool: an estimated total of 1500–2400 Pg or Gt C (Giga ton = 10^{15} g) up to 1m [7-9] Batjes, 2016;. Anthropogenic CO_2 emissions are about 9.4 Gt C per year (2400*0.04=9.6) [10]. SOC represents a stock of around 1,500–2,400 Gt C (~5500–8800 Gt CO2) in the top metre of soils globally [2]. For India, a recent study has estimated total soil carbon pool of 35.55 PgC dominated by SOC (22.72 PgC) than SIC (12.83 PgC) [11]. Globally, soils are the largest carbon reservoirs of the terrestrial carbon cycle, potential and viable sinks for atmospheric carbon but the soil OC content is declining at an alarming rate. On a global scale, the quantity of soil C exported by lateral erosion is estimated at 0.3–1 Gt C/year [12,13]. Some studies carried out on differently aged rubber plantation in the region have shown a potential net loss of SOC stock to the tune of 67.3 Mg C ha^{-1} [14].

The content of SOC is one of the main indicators of the soil quality and health [15,16]. SOC composition influences soil productivity by determining the physical, chemical, and biological soil characteristics (Kibblewhite, Ritz, and Swift 2008); Liu *et al.*2011), and SOC increase can reduce fertilizer input and irrigation, raise the harvest, and cover the yield gap [17,18]. Therefore, it is important to maintain C content in soil for avoiding degradation and implementing sustainable productivity management (Lal 2014); Campbell and Paustian 2015). The carbon-based GHGs emitted by soil, affect global warming (IPCC 2014] [19].Consequently, a small change in dynamic soil carbon content could have great effects on climate change and global warming (Galvin and Jones 2009; Zhang *et al.*2016), as well as on the indicators of soil quality and plant productivity.

There is widespread agreement that agricultural practices diminish the amount SOC stored in soil [20]. Accordingly, SOM continuous decline without optimum management ultimately causes land degradation [21]. Hence, SOM management is important to many soil properties related to ecosystem function and plant growth (Powlson *et al.*2011). Long-term experiments indicate that losses of up to 0.69 t carbon ha−1 yr−1 in the soil surface layers are common [22]. Large soil C amount was lost through poor traditional farming practices. SOC content below 1% creates problem to obtain potential crop yields with sustainability, also less than 2% makes soil aggregates unstable [23]. The C holding capacity is, however, vulnerable to disturbances, among which agricultural activity plays the leading role in depleting soil C [2] West et al 2010) Clearing, tilling and draining these lands for food production directly intensified global climate change through releasing large amount of CO2 into the atmosphere (Lal et al 1999). Large C loss under agricultural activities has been well-documented in both observational evidence from long-term monitoring experiments (Huggins et al 1998, Matson et al 1997) and model simulations (Yu et al 2018, 2019, Spawn et al 2019).

However, the extent and rates of SOC sequestration under different land use and management practices can vary greatly depending on soil characteristics, topography and climate [3,24]. Major uncertainties in spatial SOC estimates that are extrapolated from points/pedons to continuous estimates across the land surface are related to several factors. These include measurement methods, data sources (SOC data and SOC environmental covariates) and their resolution and extent, the different periods of data collection, or using multiple modeling and evaluation strategies (Grunwald, 2009; Ogle *et al.*2010; Stockmann *et al.*2013). Thus, there is a need for study describing SOC spatial variability across local to global scales [25,26,27,28,29].

The method of Walkley and Black [30] is most frequently used because it is simple and relatively quick. Our hypothesis is that diverse cropping systems different rooting behaviour when cultivated using different management practices may have an impact on the pools of SOC and thus the quality of soil and productivity. This is more important in tropical and subtropical region where soils are inherently low in organic C content and production system is fragile. In addition, the soil organic carbon estimations are basically for the purpose of soil fertility or health assessment. However, in the context of carbon sequestration and green house gas emission studies, carbon stock in soil need to be quantified for which precise estimation of soil carbon is required. Further methods and models for the assessment of SOC changes at a spatial resolution relevant for decision making in land-use issues are not yet sufficiently elaborated [31]. Understanding the current amount and spatial distribution of SOC can help to quantify and track C, which can help to sequester more C in soils to mitigate climate change concerns, geo-statistics has been applied to performed spatial interpolation Steinmann *et al.*2016..[32,33] Jackson *et al.*2017) and trends [34,35]. Knowledge of a precise amount of SOC can then be used by policymakers to incentivize the adoption of practices that will maximize SOC stocks. There is, therefore, an urgent need to more accurately estimate the organic carbon storage in soils. In this study, the spatial pattern of soil organic carbon density and organic carbon storage are investigated.

2. MATERIALS AND METHODS

2.1 Description of Study Area

Madhya Pradesh lies between 21º17′ to 26º52′ N latitude and 74º08′ to 82º49′ E longitude with geographical area of 30.82 M ha (9.4% of the country). Parent material, relief and local climate are heterogeneous in the region, thus forming many types of soils with diverse properties, depths and drainage characteristics. The soils are Inceptisols followed by Entisols, Alfisols, and Vertisols [36].

The selection was done on the basis of cropping system their prevalence in the region and significance in terms of likely variability in soil fertility status. The study was conducted in four domains namely Bhopal, Hoshangabad, Jabalpur and Vidisha where major cropping systems are soybean-wheat, soybean-chickpea, rice-wheat-summer moong, rice-wheat and soybean-wheat predominantly were selected. Medium black soil is found in the site which is good for crops like wheat, gram and soya bean. The climate and soil patterns have strong impacts on the spatial distribution of soil organic carbon density.

Four sites (clusters viz. I-domain at Jabalpur Agro-climatic zone (ACZ)-III Kamure plateau and satpura hills, II-domain Hoshangabad ACZ-V Central narmada valley, IIIrd –domain at Bhopal, Sehore and Vidsha ACZ IV-Vindhyan plateau) were taken for study during 2018-21. The latitude, longitude, and elevation at each sampling point were recorded using a handheld GPS. The coordinates of four different domains *viz.,*

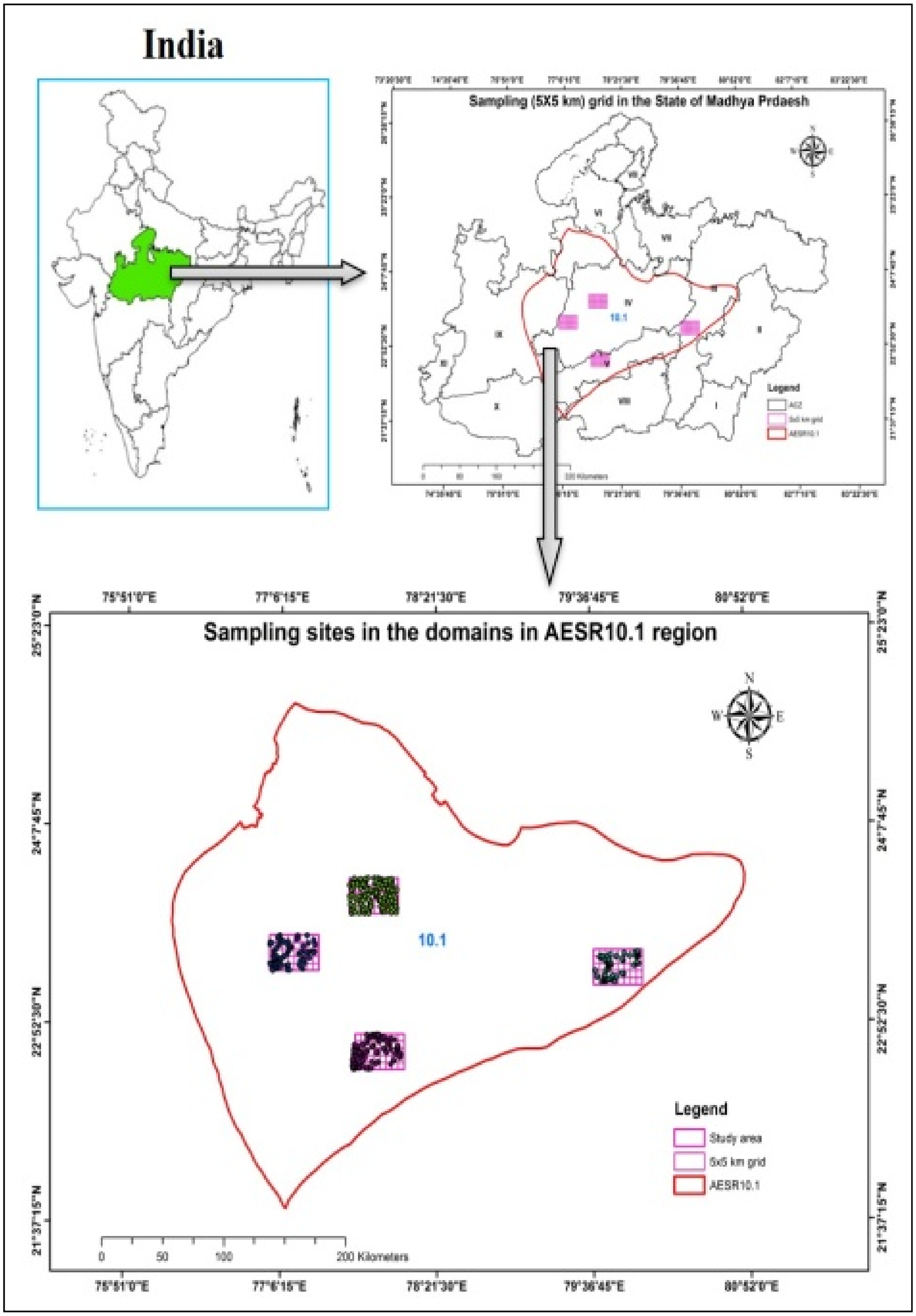


Fig. 1. Location of study area

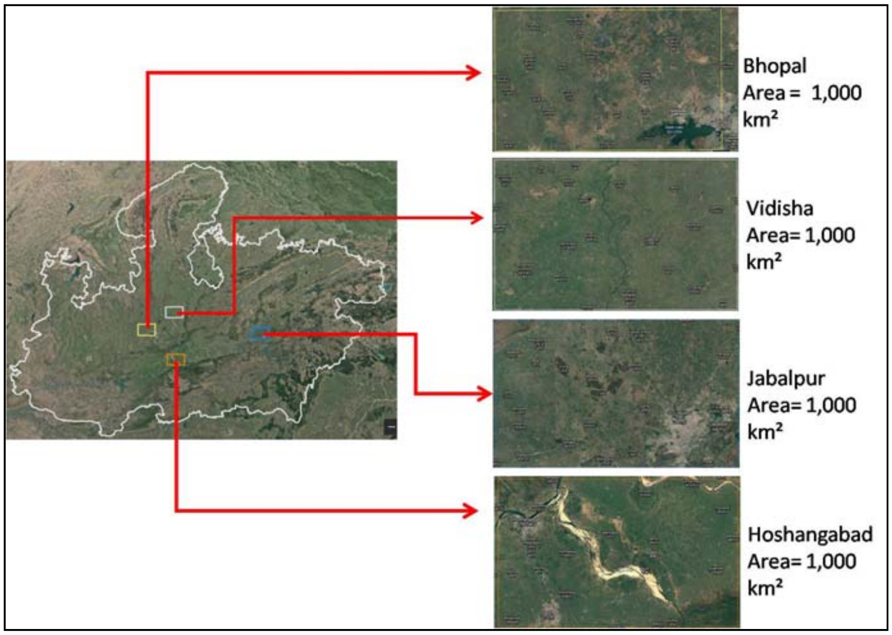


Fig. 2. Geographical location of 4 sites

Table 1. Coordinates of studied sites

	Hoshangabad	Bhopal	Vidisha	Jabalpur
GPS location	22°35'45" N to 23°49'30" N latitude and longitude is 77°40'10" E to 78°04'15" E longitude. 229 mmsl	23°15'45" N to 23°26'45" N and longitude is 76°01'15" E to 76°24'30" E.	23o35'15" N to 23o48'30" N and longitude is 77o39'15" E to 78o02'15" E	23°08'15" N to 23°20'45" N and longitude is 79°37'45" E to 80°01'30" E 383.3 m sl
Cropping system	Rice-wheat Rice-wheat summer moong Soybean-wheat	Soybean-wheat Soybean-chickpea	Soybean-wheat Soybean-chickpea	Rice-wheat Rice-chickpea
Soil order	deep black soil, clay to sandy loam in texture	Inceptisols		Vertisol,

2.2 Sites Selection, Soil Sampling and Processing and their Analysis

On a 5*5 km grid across the study area in 2018-2020 and randomly selected and GPS based Soil samples (0-15 cm) were collected from the selected sites during September-October after harvest of *Kharif* crops and March-June after harvest of *Rabi* crops. The samples were processed and analyzed.

2.2.1 Selection of sites

We performed multi-layer thematic overlay analysis in GIS environment (Arc-GIS v10.3.1) in order to identify representative soil sampling locations from agricultural land uses by employing Survey of India (SOI) topo-sheets (RF 1:50000) as base map. Thematic layers of the valley i.e. geology, physiography, elevation, slope, LULC etc. were sourced from the Bhuvan web mapping service of National Remote Sensing Centre (NRSC: http://bhuvan.nrsc.gov.in/gis /thematic) which were originally derived from LISS III image of Indian Remote Sensing satellite (IRS-P6) by NRSC (2018–2019). Apart from this, the slope aspects were derived from Digital Elevation Model (ASTER-GDEM). Thereafter, we selected 531 geo-referenced points following random sampling technique across major cropping systems.

2.2.2 Soil sampling

GPS based a total (531) five hundred thirty one surface soil samples (0-15 cm) were collected from farmer’s field *viz.,* Bhopal (n=105), Jabalpur (n=142), Vidisha (n=153) and Hoshangabad (n=131) during 2018-2020 during the off season from the agricultural land to avoid the effect of fertilization during crop cultivation. For each sampling point, 1.0 kg of representative composite soil sample was collected and logged into properly labelled sample bag. During soil sampling, spatial information (latitude and longitude), topography, slope, elevation, land use type, crop type, local soil name, soil colour, crop residue management, rate of last year fertilizer application and type were collected from each site.

2.2.3 Bulk density

The bulk density (BD) of the soil was measured from undisturbed soil samples collected using a core sampler after drying the core samples in an oven at 105 °C [37]. Core method [38].

2.4 Soil Organic Carbon (SOC)

SOC in the soils was determined by wet dichromate oxidation method of Walkley-Black [39].

2.5 Soil Inorganic Carbon

Soil inorganic carbon is estimated by standard acid-base titration [37], (Jackson, 1973).

2.6 Computation of Soil Carbon Density

The SOCD as well as SICD content will be computed by the formula suggested by Batjes, [40]:

$$\text{SOC} = Ci * Di * Ei\ (1- Gi) \qquad (1)$$

If 1ha is 10^8 cm^2 and if the soil thickness z has k level of layers, the total stock of SOC/SIC can be obtained by the adding the k stock levels, this sum of thickness Ei must be equal to z:

Total carbon content (SOC / SIC) =

$$\sum_{i=1}^{n} Ci * Di * \overset{k}{\underset{i=1}{Ei}}\ (1- Gi) * 10^8\ \text{g/ha} \qquad (2)$$

Calcium carbonate equivalents were converted to SIC content by multiplying them by 0.12, the mole fraction of C in $CaCO_3$ [41]. Based on the above principle following threshold values ≤ 0.03 %,0.03% to <0.25%,0.25% to <0.52%,0.52% to <0.75%,and ≥0.75% were fixed for identifying of Very high, high, Medium, low and very low potential area for carbon sequestration Velayutham et al. [42].

2.7 Geo-statistical Analysis in Arc GIS Environment

Geo-statistical methods were used to analyze the spatial correlation structures of soil properties and spatially estimate their values at unsampled locations using geo-statistical tool in GIS 9.3.1 software. Logarithmic transformations were used to normalize the dataset. Semiariogram ŷ(h) is computed as half the average squared difference between the soil properties of data pairs. The structure of spatial variability was analyzed through semivariograms.

$$\hat{Y}(h)=\frac{1}{2N(h)}\sum_{\alpha=1}^{N(h)}[(z(\mu_{\alpha})-z(\mu_{\alpha}+h)]^2$$

Where, N (h) is the number of data pairs separated by lag distance h; z (uα) is measured value at point a; and z (uα+h) is measured sample value at point uα+h.

Next, this was generally fitted with a theoretical model, such as Exponential, Spherical J-Bessel K- Bessel, Stable and Gaussian models for the analysis of the spatial variability of carbon density, Choice of the best- fitted model was based on the lowest residual sum of square (RSS) and the largest coefficient of determination (R^2). Nugget is the variance at distance zero, sill is the semi- variance value at which the semi-variogram reaches the upper bound after its initial increase, and range is a value (x axis) at which one variable becomes spatially independent. Semivariance estimations may depend on the parameters such as being intervals, number of lags and anisotrophy. Experimental semivariograms were fitted by theoretical models with parameters viz. nugget (Co), sill (Co+Cj) and the range of spatial dependence (a). Cambardella *et al. [43]* proposed the calculation of a dependence degree (DD) expressed as a ratio between the nugget effect value (C0) and the sill (C0+C1) and classified as Weak if DD > 75%, Moderate for 26% < DD <75%, and Strong for DD < 25% .

DD = 100*(C1/C0 +C1)

3. RESULTS AND DISCUSSION

The soil carbon density was determined up to 0.15 meter soil depth and data are presented in Table 1 and Fig. 3. The SOCD, TOCD, SICD and TCD ranged from 4.73 to 25.12, 9.22 to 48.98, 1.00 to 21.29 and 11.08 to 68.80 Mg C ha^{-1} with mean value of 12.19, 23.78, 7.58 and 31.36 Mg C ha^{-1} in AESR 10.1 as a whole and CV 37.58, 37.58, 50.88 and 31.24 %. It is evident from the table that, the soil organic carbon density in domains wise and the soil inorganic carbon density were as follows:

3.1 Soil Organic Carbon Density (OCD) (Mg C ha^{-1})

The overall trend in OCD was Bhopal > Vidisha > Jabalpur > Hoshanagabad. In Bhopal domain, it varied with a CV of 24.37% from 9.17 to 24.85 with a mean value of 17.24 Mg C ha^{-1}. In Vidisha, it hovered around a mean value of 12.65 and ranged from 6.29 to 25.12 Mg C ha^{-1} with a value of CV of 35.96%. The Jabalpur domain exhibited a mean OCD of 10.28 with a range from 4.73 to 18.33 Mg C ha^{-1}. The Hoshanagbad domain exhibited a mean OCD of 9.72 with a range from 5.33 to 15.85 Mg C ha^{-1}. Though, the mean OCD is comparatively low in Hoshangabad domain. The Bhopal domain showed comparatively higher OCD and the lowest variability than others in this particular domain. It is evident that such a result is directly linked to the amount and quantity of organic residues return to the soils. As plant material has higher C-to-N ratios than SOM, a steady increase in the C-to-N ratio of SOM could facilitate soil C sequestration without extra N. The return of legume biomass can maintain organic matter and increase nutrient content in the soil (Wijanarko *et al.*2017). FYN addition and cropping sequence followed in this area might be affected the SOC density. Less intensive practices enhance aggregate soil stability in soil that slows down decomposition of organic a matter by providing protection within the soil aggregates [44]. Some studies were relevant to this elsewhere by Kuo et al. [45], Hartwig and Ammon [46], Halvorson et al. [47]. In the present study, Hoshangabad and Jabalpur domain exhibited less organic C density which could be attributed to intensive cultivation [48,49]. lesser soil SOCD content in these domains than the others implies a considerable depletion of SOC stock by these land use types through alterations of plant species and management practices Hall and Lemon [50]. Yimer et al. [51] also found that soil organic carbon less in croplands and abundant of surface soil. The change of the SOC content is affected by climate conditions and soil background nutrients in the study area. Organic carbon mainly comes from residues of plants, animals, microbial, and root exudates, and its content varies in the dynamic process of continuous decomposition and formation Zhang *et al.*[52] SOC depends on input intensity from cropping system and composition (or quality) of SOM (Gaiser and Stahr 2013). According to Scotti *et al.*(2015), organic amendment such as compost could be a sustainable medium to improve C content and soil fertility in intensive agriculture. Moreover, applying organic matter can reduce erosion and nutrient leaching in the soil. Post burn cultivation results reduction of TOC as well as considerable variation in the proportion of different SOC pools to TOC concentration. This loss is more in the active pool (very labile and labile) than the passive pool (less labile and non-labile) of SOC. The low organic carbon content in Vertisols was also reported by Chouhan *et al.*2012. The content of organic carbon in soils is dependent on the bioproductivity and the mineralization intensity of organic matter, which are strongly controlled by hydrothermal conditions and soil texture Vitousek *et al.*(2010). The lower SOC is probably due to relatively low rates of return of crop residues to the soil and high rates of carbon loss caused by a combination of excessive tillage, burning of crop residues, high growing season temperatures, and wet soils as a consequence of irrigation [53]. In study excessive tillage and intensive cultivation might be reduced soil organic carbon density this was supported by but Singh *et al.*[49] but elsewhere. The soil organic carbon density varied with different domain where land use management practices have the most influence (Su *et al.,*2006). Land use is the main factor that determines SOC amount and distribution (Navarrete and Tsutsuki 2008). Vegetation type has an important role in carbon dynamics by affecting the nutrient cycle (primarily N and P) (Fang *et al.*2015). It can influence the distribution pattern of SOC depth by plant cycle and root distribution change (Bai *et al.*2016). Furthermore, SOC distribution is strongly affected by management practices, especially tillage systems, in which soil environment is altered (Matsumoto, Paisancharoen, and Hakamata 2008). This change in the soil environment will influence SOC retention or accumulation under various soil horizons (Olson and Al-Kaisi 2015). SOC change caused by management is generally restricted to surface soil (Franzluebbers 2014). Moreover, Xue and An (2018) also expressed that the effect of land use on SOC was the most significant on topsoil. The variation in SOC is due to the variation in texture [54,55] and mineralogy [56,57] of soils. Tillage decreases C stocks in soils by exposing SOC to microbial activity through destruction of aggregates and the release of soil C [44].

3.2 Total Organic Carbon Density (TOCD) (Mg C ha^{-1})

Data are presented and in Table 2 and Fig. 4 on total organic carbon density showed the overall trend in TOCD was Bhopal > Vidisha > Jabalpur > Hoshanagabad. In Bhopal domain, it varied with a CV of 24.37 % from 17.89 to 48.45 Mg C ha^{-1} with a mean value of 33.62. In Vidisha, it hovered around a mean value of 24.66 and ranged from12.27 to 48.98 Mg C ha^{-1} with a value of CV of 35.96 %. The Jabalpur domain exhibited a mean TOCD of 20.05 with a range from 9.22 to 35.75 Mg C ha^{-1}. The Hoshanagbad domain exhibited a mean TOCD of 18.96 with a range from 10.38 to 30.91 Mg C ha^{-1}. Though, the mean TOCD is comparatively low in Hoshangabad domain. The Bhopal domain showed comparatively higher TOCD and the lowest variability than other was observed in this particular domain. A strong oxidative force of high temperature (during peak summer months, temperature goes up to 40°– 45°C) compared with the cooler and temperate regions coupled with the disrupting effects of ploughing for intensive cropping led to a rapid oxidation of SOC in this region Mandal et al. [58]. Because of the known ability of clays to sorb and protect OM from degradation [59], one might expect to find a positive relationship between TOC and extractable C pools and clay, and a negative relationship between C_{min} rate and clay content. Velayutham *et al.* [42] states that, carbon amounts are low on farming area such as Vertisols because of intense cultivation systems Sakin and Mermut [60] in their research show that farming activities cause 57% decline on carbon stocks rate. Ardo and Olsson (2003) Li et al. [61] Raheb et al. [62] and Zhong et al. [63].

3.3 Soil Inorganic Carbon Density (SICD) (Mg C ha^{-1})

It is evident from data presented in Table 3 and Fig. 5 of soil inorganic carbon density which was determined up to 0.15 meter soil depth showed the overall trend in ICD was Vidisha > Hoshanagabad > Jabalpur >Bhopal. In Vidisha, it hovered around a mean value of 9.45 and ranged from 1.22 to 21.29 Mg C ha^{-1} with a value of CV of 40.65%. The Hoshanagbd domain exhibited a mean ICD of 8.60 with a range from 1.00 to 18.94 Mg C ha^{-1} and a value of CV of 53.32. The Jabalpur domain exhibited a mean ICD of 5.82 with a range from 1.13 to 12.06 Mg C ha^{-1} and a value of CV of 39.25. In Bhopal domain, it varied from 1.10 to 11.59 with a mean value of 5.94 Mg C ha^{-1} and with a CV of 45.45%. Though, the mean SICD is comparatively low in Bhopal domain and Hoshanagabad domain it showed the highest variability. The Vidisha domain showed comparatively higher SICD than other. The SICD of soils was affected by domains. Considering this, the highest and the lowest values were observed on the surface (0-15 cm) soil layer of Vidisha and Bhopal domains, respectively. Higher atmospheric temperature associated with low rainfall is responsible for high content of secondary carbonates. Calcium carbonates reported in the humid and perhumid region is considered mostly as inherited material in soils developed from strongly calcareous parent material, usually on young geomorphic surfaces. The SIC stock is relatively high in arid and semi-arid ecosystem [42].

3.4 Total Carbon Density (TCD) (Mg C ha^{-1})

The total carbon density was determined up to 0.15 meter soil depth and data are presented in Table 3 and Fig. 6 The overall trend in TCD was Bhopal > Vidisha > Hoshangabad> Jabalpur. In Bhopal domain, it varied with a CV of 22.08% from19.74 to 57.73 with a mean value of 39.56. In Vidisha, it hovered around a mean value of 34.11 and ranged from 17.19 to 68.80 Mg C ha^{-1} with a value of CV of 32.09 %. The Hoshanagbd domain exhibited a mean TCD of 27.56 Mg C ha^{-1} with a range from 12.62 to 43.34 and a CV of 21.60%. The Jabalpur domain exhibited a mean TCD of 25.87 Mg C ha^{-1} with a range from 11.08 to 42.68 Mg C ha^{-1} and a CV value of 24.54. The CV is comparatively low in Hoshangabad domain and TCD was least in Jabalpur domain this might be due to the heavy compactness of the soil. This could be in turns hamper an accumulation of soil TCD. The Bhopal domain showed comparatively higher TCD than other this could be due to soybean-chickpea and soybean-wheat and rooting systems in, which have fine and short roots while cultivated land has large, and long roots of crops, which can play a great contribution in the enhancement of TCD. Moreover, the highest value of soil TCD was attributed to the excessive amount of plant residues and biomass on surface land. Our finding is in agreement with those of Iqbal et al.[64] and Takele et al. [65].

3.5 Spatial Variability Maps Generated Using Geo-Statistical Tool

Ordinary Kriging was chosen to create the spatial distribution maps of soil characteristics with maximum search radius being set to autocorrelation range of the corresponding variable.

3.5.1 Characteristic of semi-variogram

Semi-variogram used for analysis distribution of OCD, TOCD, SIC and TC are presented in Table 2 and figures depicted in 7 (a,b,c,d), 8 (a,b,c,d), 9 (a,b,c,d), and 10 (a,b,c,d) of Bhopal, Hoshangabad, Jabalpur and Vidisha, respectively.

In this study, all variogram were in isotropic form and were fitted using basic math models, such as Spherical, Exponential, Gaussian, and J-Bessel based on the values of weighted residual sums of squares and relative spatial structure indicator (Nugget/Sill) that indicated spatial dependency. Filled contour maps (Prediction map) were created and geo-statistical result are interpreted are as follows: For of OCD, TOCD, SIC and TC in Bhopal domain, Gaussian model best fitted for of OCD, TOCD, and TC but Spherical model for SIC. In Jabalpur domain, Exponential domain best fitted for TC and TOCD but for SIC, Spherical model and for OCD, Gaussian model is best fitted. In Vidisha domain, Exponential model best fitted for all i.e., for OCD, TOCD, SIC and TC. And in Hoshangabad domain, Exponential model is best fitted for OCD and TOCD, and Gaussian and J-Bessel model best fitted for TC and SIC, respectively.

The SOC distribution depended on large scale factors as regional climate, vegetation, soil type and topography (Su et al.2006; Wang et al.2010). It has been stated recently that Vertisols showing typical vertic properties can only be because of smectite content (Bhattacharyya et al.1997) to the tune of at least 20% (Shirsath et al.,2000). Presence of smectite increases the soil carbon density of soils, which offers greater scope of carbon sequestration in Vertisols. In addition, hot and dry climate is directly related with the temperature variation in the region. Organic carbon was also attributed to variation in decomposition rate and the spatial variability in soil organic carbon content. Similar results were reported by Liu et al.[66] and Noor and Shah [67] who reported that exponential model was best fitted for SOC.

The nugget/sill (N/S) ratio was <25% which exhibit strong spatial dependency only for SIC in Bhopal domain. The N/S ratio was found to be >25% but <75% which showed moderate spatial dependency, for OCD, TOCD, and TC for Bhopal domain, TOCD, SIC and TC in Jabalpur domain, OCD, TOCD, SIC and TC in Vidisha domain, and OCD, TOCD, SIC and TC in Hoshangabad domain. The N/S ratio was found to be <75% which showed weak spatial dependency for SOCD in Jabalpur domain and none in Bhopal, Vidisha and Hoshangabad domain.In Bhopal domain, correlation range (m) for OCD, TOCD, SIC and TC are 5448.413, 4809.535, 360.522, and 5113.050, respectively. In Jabalpur domain, correlation range (m) for OCD, TOCD, SIC and TC are7201.044, 6601.044, 611.651, and 8438.711, respectively. In Vidisha domain, correlation range (m) for OCD, TOCD, SIC and TC are5734.559, 7334.398, 1323.773, and 7881.289, respectively. In Hoshangabad domain, correlation range (m) for OCD, TOCD, SIC and TC are5418.684, 5433.206, 8887.656, and 1836.274, respectively. Usually, a strong spatial dependence of soil properties could be attributed to intrinsic factors and a weak spatial dependence could be attributed to extrinsic factors Cambardella et al. [43] and Spatial distribution maps showed the patches of soil carbon density and showed variation across the domains which used for prioritizing carbon sequestration potential zone of the domains. Vasu et al. [68,69], 2020, Reza et al.2012, Paustian et al. [4] Smith et al. [70] also study elsewhere.

Table 2. Descriptive statistics of soil carbon density in different domains

Domain	Mean	Min	Max	Range	Median	SD	SE	CV%	Variance	Kurtosis	Skewness
	SOCD (Mg C ha^{-1})										
Bhopal	17.24	9.17	24.85	15.68	17.29	4.20	0.41	24.37	17.66	-1.10	0.04
Jabalpur	10.28	4.73	18.33	13.60	10.00	2.99	0.25	29.08	8.94	-0.01	0.60
Vidisha	12.65	6.29	25.12	18.83	11.59	4.55	0.37	35.96	20.68	0.09	0.93
Hoshangabad	9.72	5.33	15.85	10.53	9.30	2.56	0.22	26.37	6.57	-0.81	0.42
AESR 10.1	12.19	4.73	25.12	20.39	11.21	4.58	0.20	37.58	21.00	0.13	0.90
	TOC D (Mg C ha^{-1})										
Bhopal	33.62	17.89	48.45	30.57	33.71	8.20	0.80	24.37	67.16	-1.10	0.04
Jabalpur	20.05	9.22	35.75	26.53	19.50	5.83	0.49	29.08	34.01	-0.01	0.60
Vidisha	24.66	12.27	48.98	36.71	22.60	8.87	0.72	35.96	78.65	0.09	0.93
Hoshangabad	18.96	10.38	30.91	20.53	18.13	5.00	0.44	26.37	24.98	-0.81	0.42
AESR 10.1	23.78	9.22	48.98	39.76	21.85	8.94	0.39	37.58	79.85	0.13	0.90
	SICD (Mg C ha^{-1})										
Bhopal	5.94	1.10	11.59	10.49	6.16	2.70	0.26	45.45	7.28	-0.58	-0.11
Jabalpur	5.82	1.13	12.06	10.92	5.82	2.29	0.19	39.25	5.22	0.22	0.30
Vidisha	9.45	1.22	21.29	20.07	9.19	3.84	0.31	40.65	14.76	-0.05	0.38
Hoshangabad	8.60	1.00	18.94	17.94	8.21	4.59	0.40	53.32	21.03	-0.81	0.17
AESR 10.1	7.58	1.00	21.29	20.29	7.13	3.86	0.17	50.88	14.88	0.19	0.62
	TCD (Mg C ha^{-1})										
Bhopal	39.56	19.74	57.73	37.99	39.31	8.73	0.85	22.08	76.30	-0.85	0.11
Jabalpur	25.87	11.08	42.68	31.60	25.36	6.35	0.53	24.54	40.33	0.13	0.40
Vidisha	34.11	17.19	68.80	51.61	32.01	10.95	0.89	32.09	119.84	0.33	0.85
Hoshangabad	27.56	12.62	43.34	30.72	27.55	5.95	0.52	21.60	35.41	0.17	0.08
AESR 10.1	31.36	11.08	68.80	57.72	29.57	9.80	0.43	31.24	95.97	0.60	0.85

Table 3. Characteristics of semi variogram of soil carbon density in various domains

Domain(n)	parameter	Model	Range(m)	Nugget	Partial Sill	Sill	NS ratio	lag size(m)	RMSS	ASE
Bhopal	SOCD	Gaussian	5448.413	5.2093101334	11.8859376585	17.0952477919	0.30	612.298	0.846	3.127
Jabalpur	SOCD	Gaussian	7201.044	7.3111254236	2.2488885351	9.5600139587	0.76	600.087	1.048	2.881
Hoshanagabd	SOCD	Exp.	5418.684	2.7203490351	4.3219424040	7.0422914391	0.39	908.715	0.933	2.402
Vidisha	SOCD	Exp.	5734.559	14.2426924884	6.3029321123	20.5456246007	0.69	1021.200	1.013	4.511
Bhopal	TOCD	Gaussian	4809.535	19.8084017893	39.1592994617	58.9677012510	0.34	712.298	0.839	6.128
Jabalpur	TOCD	Exp.	6601.044	24.7826421042	10.2889265775	35.0715686817	0.71	550.087	1.045	5.578
Hoshanagabd	TOCD	Exp.	5433.206	10.3281819141	16.4966081640	26.8247900781	0.39	808.715	0.932	4.685
Vidisha	TOCD	Exp.	7334.398	47.4086343764	37.3605660614	84.7692004378	0.56	911.200	1.015	8.695
Bhopal	SICD	Spherical	360.522	0.0017379133	0.0124294748	0.0141673881	0.12	653.960	0.935	0.123
Jabalpur	SICD	Spherical	611.651	0.0049141927	0.0077198497	0.0126340423	0.39	480.647	1.016	0.110
Hoshanagabd	SICD	J-Bessel	8887.656	0.0322195915	0.0126187103	0.0448383018	0.72	740.638	0.875	0.202
Vidisha	SICD	Exp.	1323.773	0.0179765591	0.0132537341	0.0312302931	0.58	599.125	1.002	0.187
Bhopal	TCD	Gaussian	5113.050	25.7010197925	45.3773614825	71.0783812750	0.36	618.067	0.882	6.780
Jabalpur	TCD	Exp.	8438.711	27.7317248927	14.1596217963	41.8913466890	0.66	903.226	1.062	5.911
Hoshanagabd	TCD	Gaussian	1836.274	0.0141880257	0.0341593321	0.0483473578	0.29	406.055	1.007	0.202
Vidisha	TCD	Exp.	7881.289	74.8919968779	52.3439650991	127.2359619769	0.59	656.774	1.018	10.666

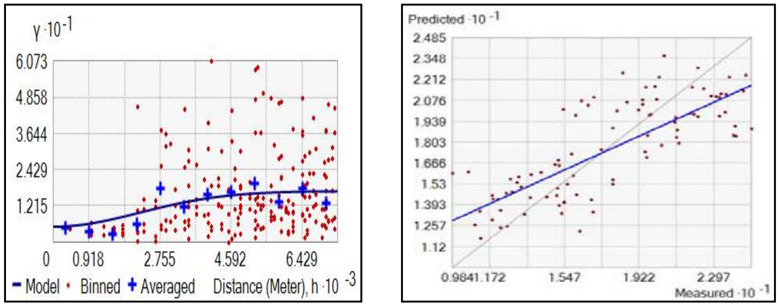


Fig. 3.a. Semi-variogram of SOCD (Mg C ha^{-1}) of Bhopal domain

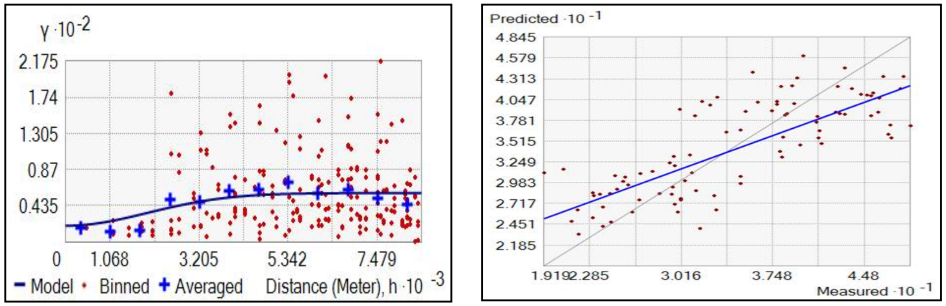


Fig. 3.b Semi-variogram of TOCD (Mg C ha^{-1}) in soils of Bhopal domain

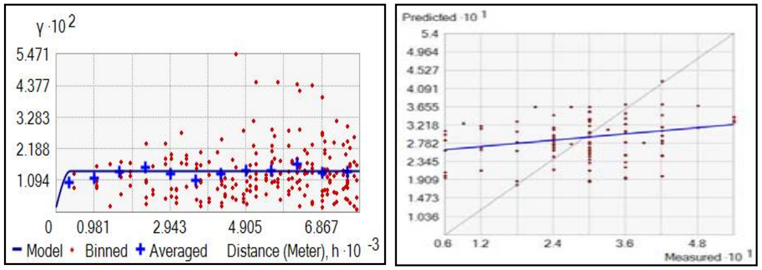


Fig. 3.c Semi-variogram of SICD (Mg C ha^{-1}) in soils of Bhopal domain

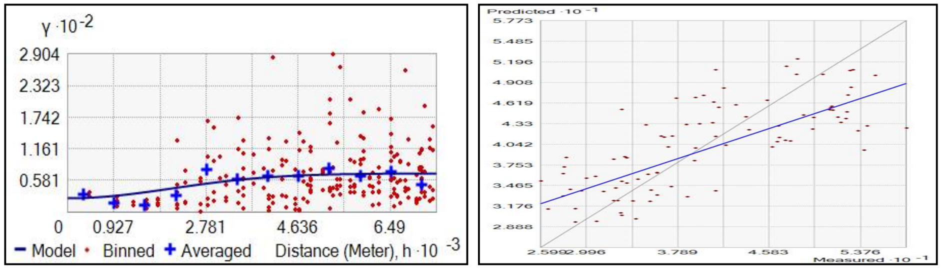


Fig. 3.d. Semi-variogram of TCD (Mg C ha^{-1}) in soils of Bhopal domain

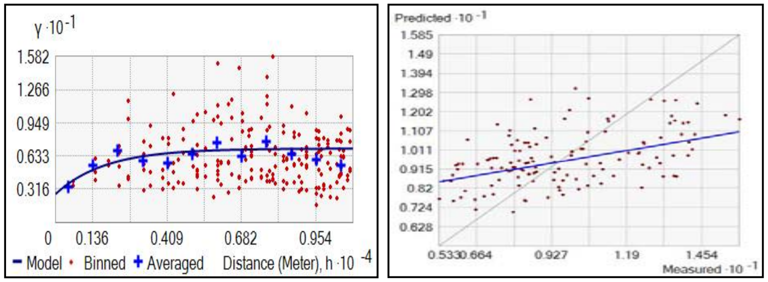


Fig. 4.a. Semi-variogram of SOCD (Mg C ha^{-1}) in soils of Hoshangabad domain

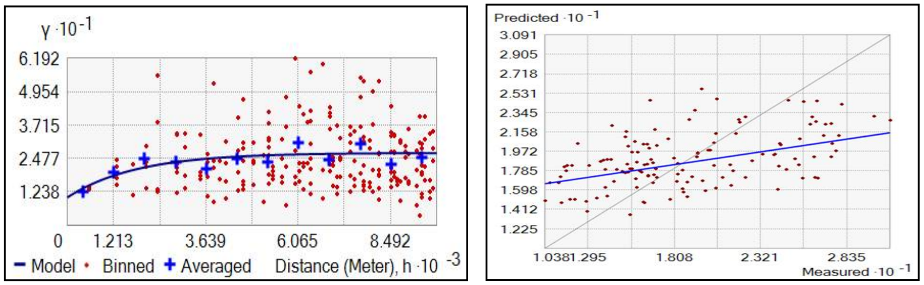


Fig. 4.b. Semi-variogram of TOCD (Mg C ha^{-1}) in soils of Hoshangabad domain

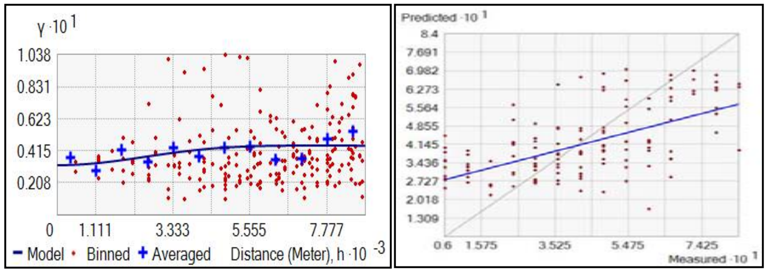


Fig. 4.c Semi-variogram of SICD (Mg C ha^{-1}) in soils of Hoshangabad domain

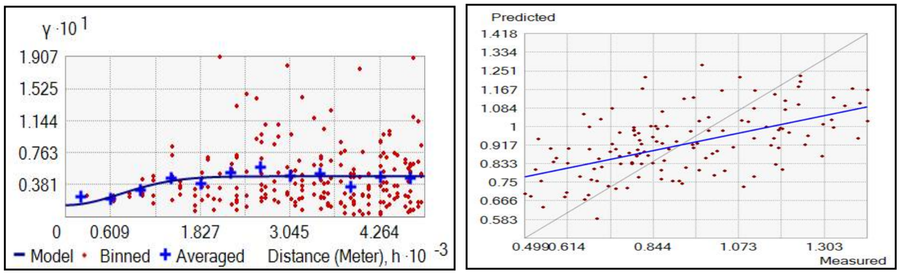


Fig. 4.d Semi-variogram of TCD (Mg C ha^{-1}) in soils of Hoshangabad domain

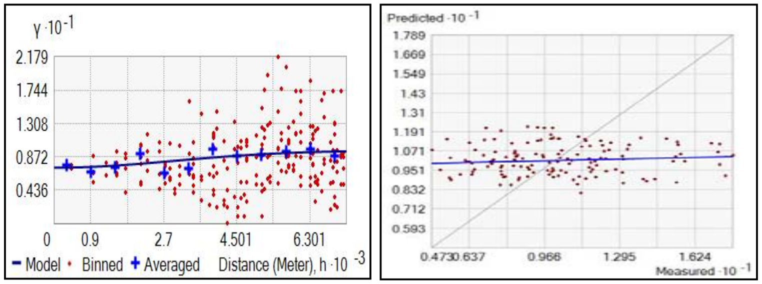


Fig. 5.a. Semi-variogram of SOCD (Mg C ha^{-1}) in soils of Jabalpur domain

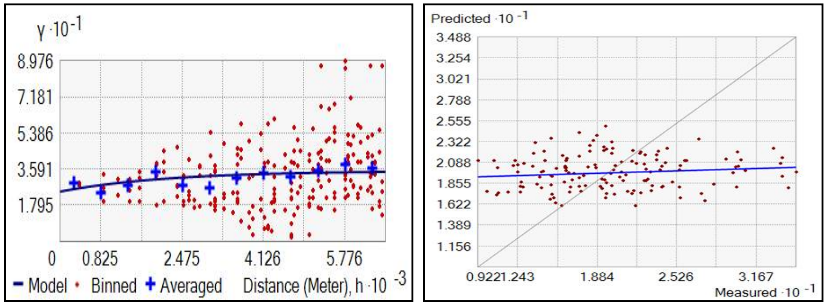


Fig. 5.b. Semi-variogram of TOCD (Mg C ha^{-1}) in soils of Jabalpur domain

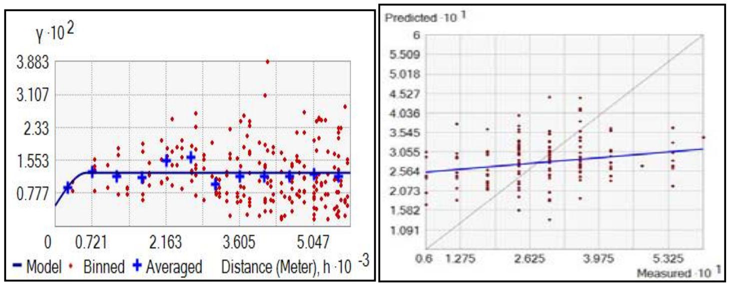


Fig. 5.c Semi-variogram of SICD (Mg C ha^{-1}) in soils of Jabalpur domain

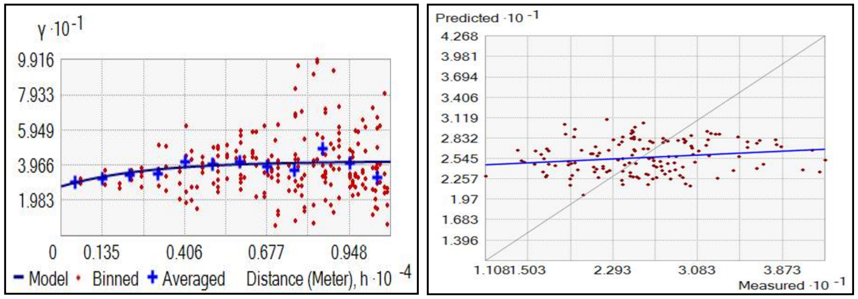


Fig. 5.d Semi-variogram of TCD (Mg C ha^{-1}) in soils of Jabalpur domain

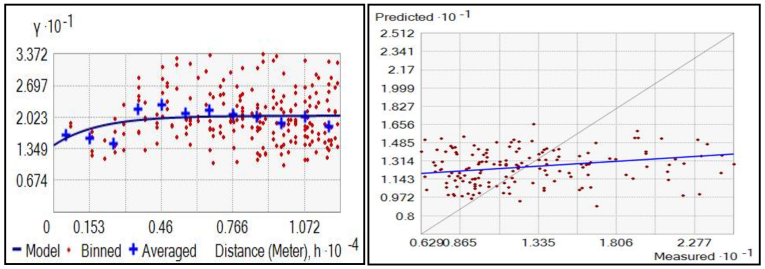


Fig. 6.a Semi-variogram of SOCD (Mg C ha^{-1}) in soils of Vidisha domain

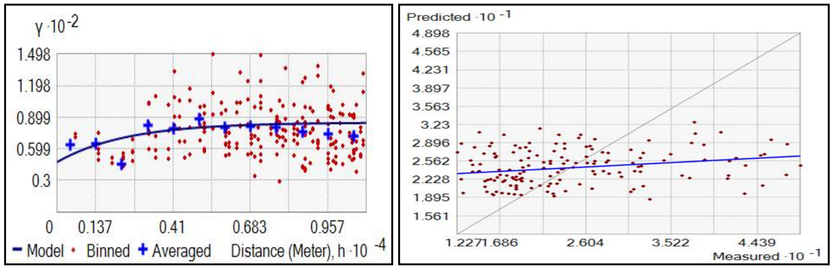


Fig. 6 .b Semi-variogram of TOCD (Mg C ha^{-1}) in soils of Vidisha domain

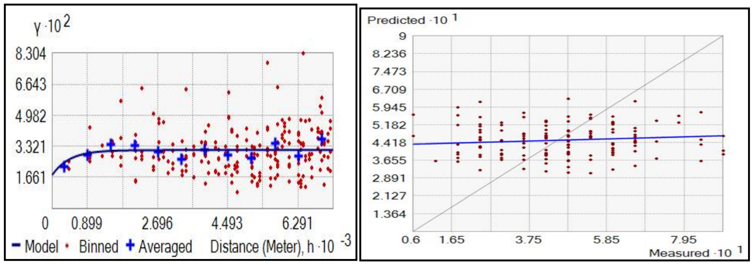


Fig. 6.c Semi-variogram of SICD (Mg C ha^{-1}) in soils of Vidisha domain

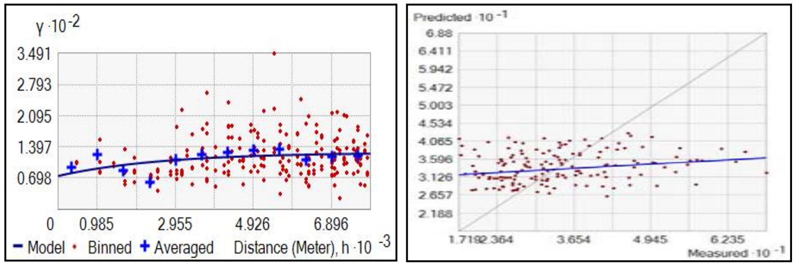
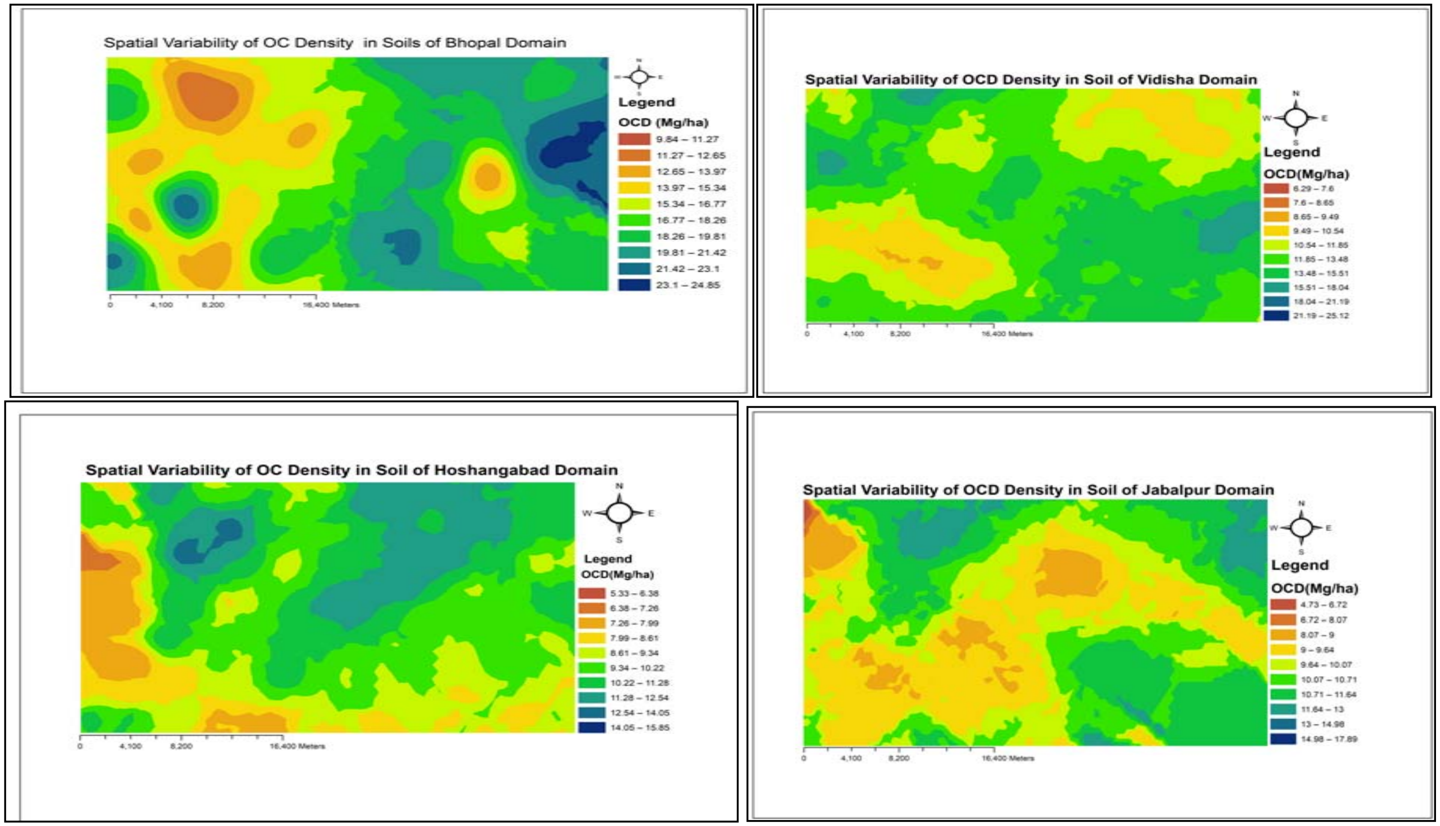


Fig. 6.d Semi-variogram of TCD (Mg C ha^{-1}) in soils of Vidisha domain



Spatial Variability of OC Density in Soils of Bhopal Domain

Spatial Variability of OCD Density in Soil of Vidisha Domain

Spatial Variability of OC Density in Soil of Hoshangabad Domain

Spatial Variability of OCD Density in Soil of Jabalpur Domain

Fig. 7. Soil Organic carbon density (Mg C ha^{-1}) of soils in different domains

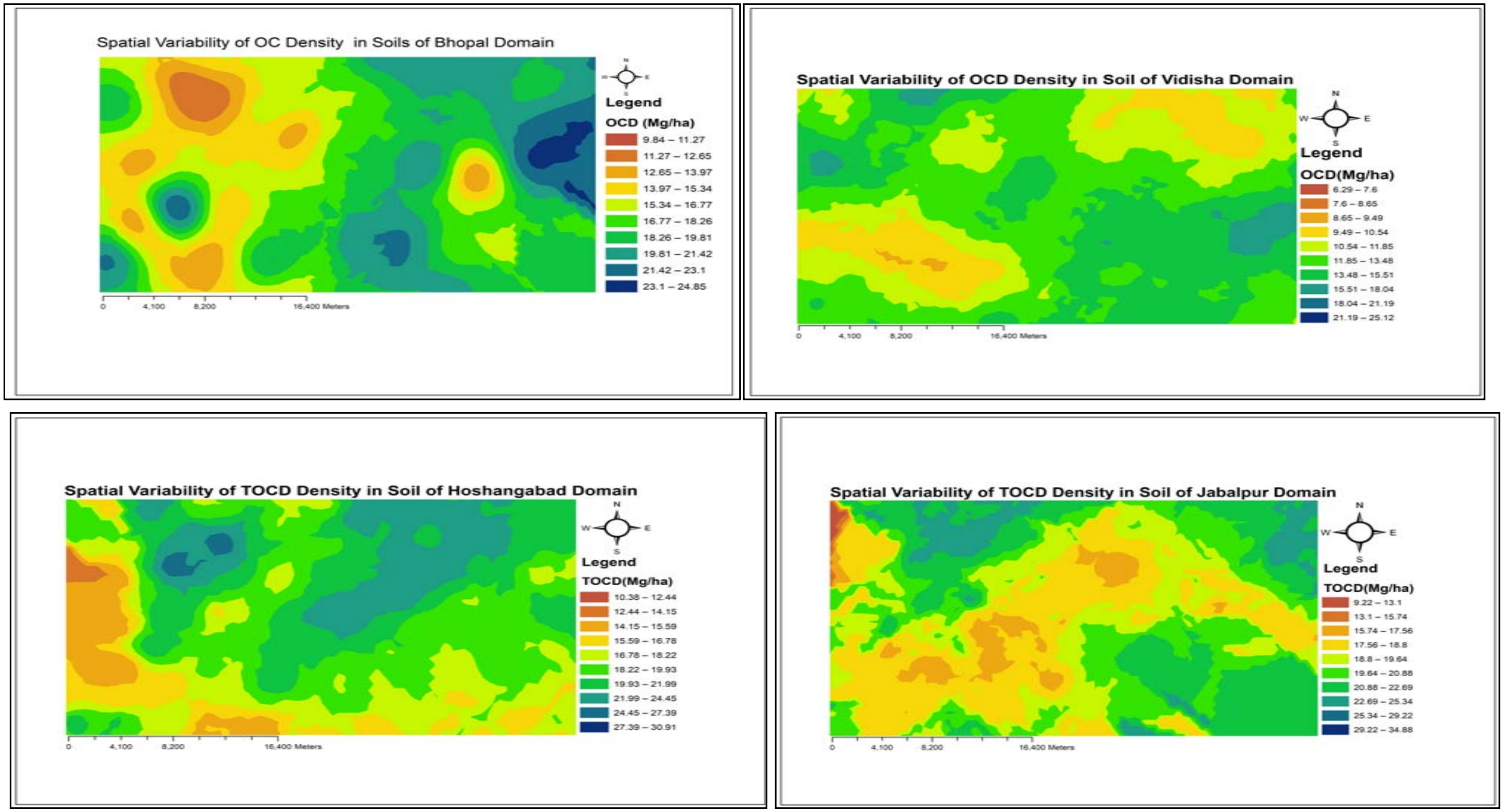


Fig. 8. Total Organic carbon density (Mg C ha^{-1}) of soils in different domains

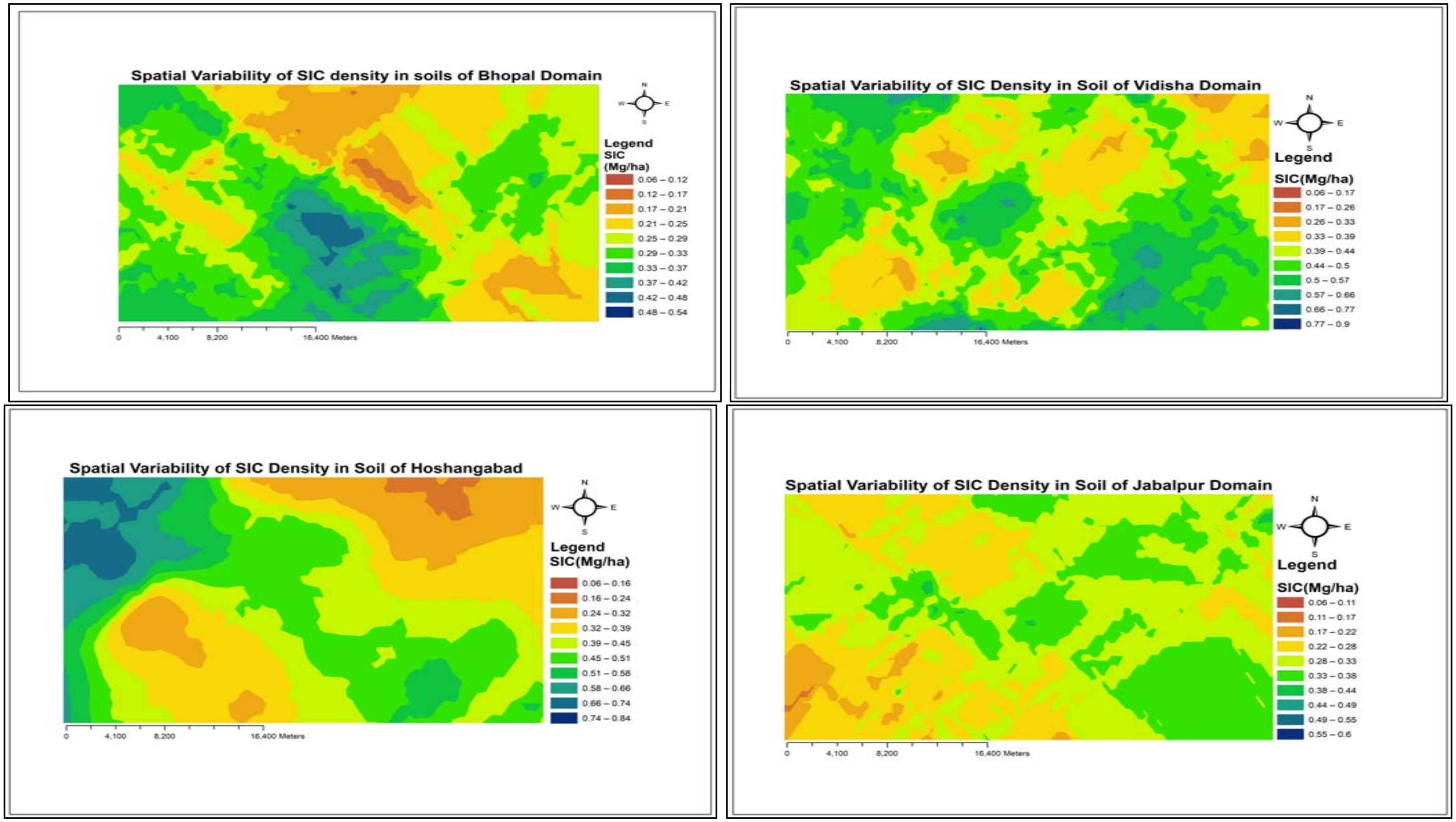
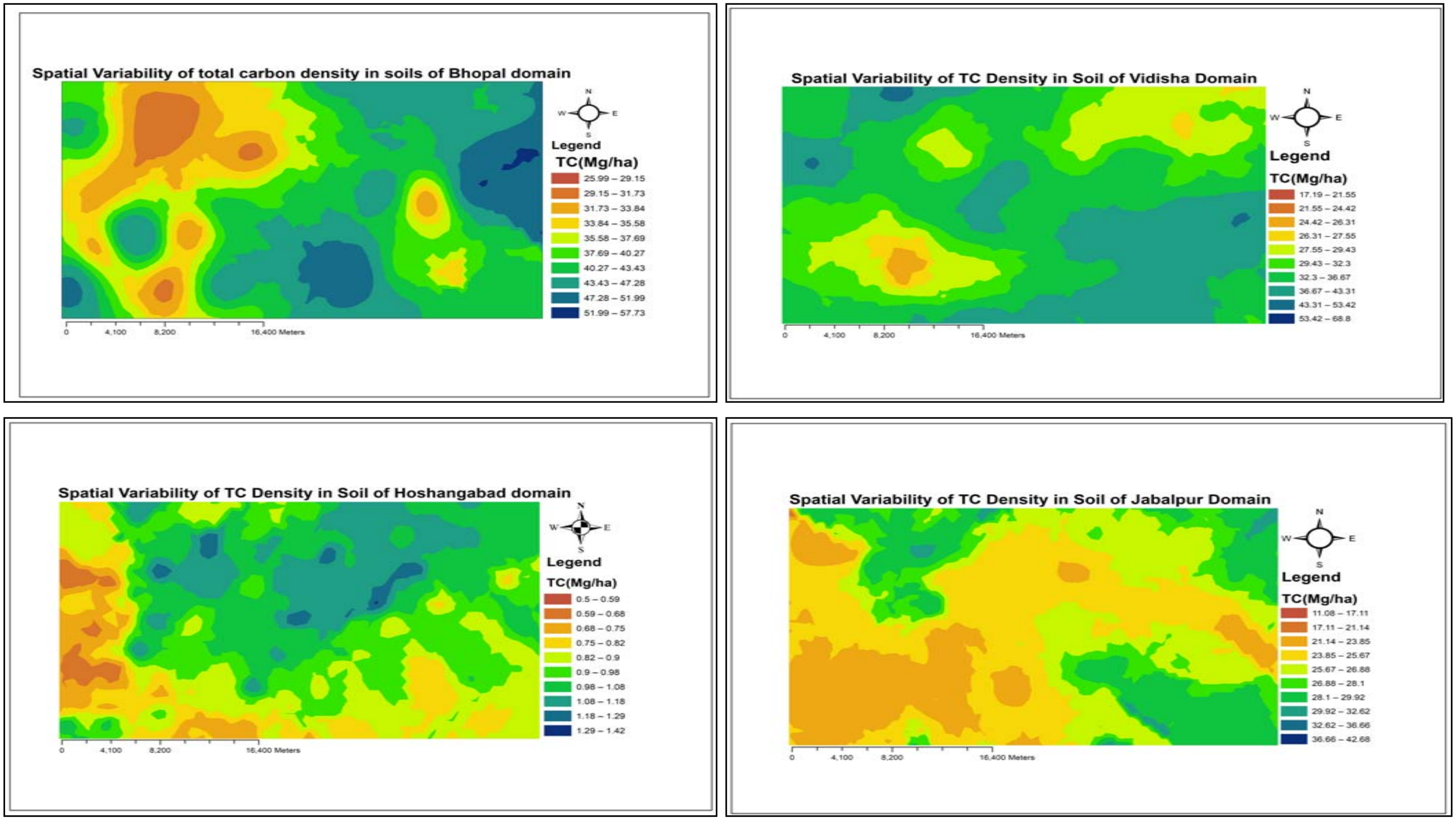


Fig. 9. Soil inorganic carbon density (Mg C ha^{-1}) of soils in different domains


Spatial Variability of total carbon density in soils of Bhopal domain

Spatial Variability of TC Density in Soil of Vidisha Domain

Spatial Variability of TC Density in Soil of Hoshangabad domain

Spatial Variability of TC Density in Soil of Jabalpur Domain

Fig. 10. Total carbon density (Mg C ha^{-1}) of soils in different domains

4. CONCLUSIONS

Soil carbon sequestration potential, is an indication of carbon status of the soil, is the most limiting factor in most cultivated lands. The results noticed that the SOCD, TOCD, SICD and TCD ranged from 4.73 to 25.12, 9.22 to 48.98, 1.00 to 21.29 and 11.08 to 68.80 Mg C ha^{-1} with mean value of 12.19, 23.78, 7.58 and 31.36 Mg C ha^{-1} in AESR 10.1 as a whole and CV 37.58, 37.58, 50.88 and 31.24 %. The overall trend in SOCD was Bhopal > Vidisha > Jabalpur > Hoshanagabad. Therefore, suggested that more potential domain for carbon sequestration were Hoshangabad and Jabalpur. Hence, proper soil and water conservation practice are important in these areas to enhance soil carbon sequestration in soil, fertility and crop productivity.

ACKNOWLEDGEMENTS

The first author of manuscript is grateful to Scientist of Department of Soil Science and Agril. Chemistry, JNKVV Jabalpur, India, for all the support and help. The author also acknowledge to Scientist of Madhya Pradesh Council of Science and Technology for their help in selecting the geo-referenced sampling sites from a land use–land cover map.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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