MULTISPECTRAL IMAGE ANALYSIS OF LANDUSE AND LANDCOVER CHANGE AND CHRONOSEQUENCE ASSESSMENT OF SOIL ORGANIC CARBON IN NATURALLY RECLAIMED OVERBURDEN DUMP IN THE RANIGANJ COAL FIELD AREA, WEST BENGAL

Surajit Chakraborty[1*], Rohit Basu Dhar[1], Pradip K.Sikdar[1], Suranjan Sinha[2]
[1]Department of Environment Management, Indian Institute of Social Welfare and Business Management, Management House, College Square West, Kolkata.
[2]Department of Mining Engineering, Indian Institute of Engineering Science and Technology, Shibpur, Howrah.
*Corresponding author Email: surajitc@iiswbm.edu

Abstract

The current study focuses on analysing landuse and landcover (LULC) changes using remote sensing and GIS, as well as carbon sequestration in naturally reclaimed overburden dump soil of an open cast coal-mine in Sonepur-Bazari, Raniganj Coalfield area, Bardhaman district, West Bengal by estimating soil organic carbon (SOC). The landuse/landcover changes over 20 years (1999-2019) due to expansion of mining and identification of overburden dump sites have been carried out using Sentinel 2B MSI and Landsat TM 5 data. The SOC in OB dump soil has been measured in chronosequence (one year, three years, five years, ten years, fifteen years, and twenty years) at two depth profiles (< 15 cm and 15-30 cm) and is compared with those of the adjoining wasteland site. The study indicates that the SOC content of the soil of the recent OB dump at <15 cm depth is 9.1 megagram per hectare or 16.70 megagram CO2 per hectare. At the same depth of a 20-year old OB dump the SOC content is 21.6 megagram per hectare (39.64 megagram CO2 per hectare). Soil samples collected from depth between 15 and 30 cm the SOC increases from 8.3 to 19 megagram per hectare (15.23 to 34.86 megagram CO2 per hectare) over twenty years' time. The SOC content in the adjoining wasteland site is 17.7 megagram per hectare (32.48 Mg CO2 per hectare) and 17.2 megagram per hectare (31.56 megagram CO2 per hectare) at depths < 15 cm and 15 to 30 cm respectively. Therefore, initially the SOC is less in recent OB dump compared to that of wasteland but within 20 years the naturally reclaimed OB dump accumulates SOC and it is 3.9 megagram per hectare (7.16 megagram CO2 per hectare) and 1.8 megagram per hectare (3.30 megagram CO2 per hectare) more than that of the wasteland at <15 cm and at 15-30cm depths respectively. This clearly indicates that SOC sequestration is dependent on biomass growth. Therefore, a scientific OB dump management program will increase the rate of carbon sequestration which will help in combating climate change at a local level.

Keywords: Landuse and landcover change. Overburden dump. Geospatial technology. Soil organic carbon (SOC). Carbon sequestration. Raniganj coalfield area.

Introduction

The concentration of CO2 has gone up from an approximate 280 ppm during pre-industrial time to about 380 ppm in 2005. The rate of CO2 increase during the last decade is 2.33 ppm/year (IPCC, 2006). It is also predicted that emission-rate of CO2 may increase from 7.4 to 26 Giga tons-C/year (Gt-C/year) between 1997 and 2100 (Houghton et al.1996). The present trend of increase in concentration of carbon dioxide (CO2) will have a variety of environmental consequences on the functioning eco-energy systems (Barnett and Schlesinger 1987; Brown et al. 1992; Lindzen 1994; Santer et al. 1995; Adams et al. 1999). One of the methods to offset CO2 concentration in the atmosphere is carbon sequestration (IPCC 2000). Studies across the globe on Carbon (C)-sequestration indicates that the rate of sequestration is much larger in marine and aquatic ecosystems than compared to terrestrial ecosystems due to the large abundance of phytoplankton.

Terrestrial C-sequestration involves two steps: (i) converting atmospheric CO2 into biomass which includes trees, bushes, plants, and soil organic matter (SOM) through photosynthesis; and (ii) incorporating humus in soil. As a result, atmospheric CO2 is effectively stored as soil organic carbon (SOC). Soil has about 75% of the terrestrial carbon pool. Carbon concentration in soil is three times more compare to that of living plants. Therefore, SOC has a tremendous impact on global carbon cycle (Schlesinger and Bernhardt 2013) however, anthropogenic LULC changes result in rapid decline in SOM (Davidson and Ackerman 1993).

Due to global warming and climate change relevance of C-sequestration have gained importance in recent times because of anthropogenic activities like deforestation, industrialization, mining, transportation, and intensive agriculture. These activities greatly increase the atmospheric concentrations of GHGs such CO2, CH4, O3, NOx, and CFCs, that may increase the air temperature (Hansen et al. 1984).

Carbon sequestration is one approach to reduce the amount of CO2 in the atmosphere by storing it in soil. Carbon can be stored in soil, as CO2, elemental carbon, and in carbon-containing minerals. Recently, there has been a lot of interest in carbon sequestration using recovered coal mine soils (IPCC 2000; Akala and Lal 2000, 2001; Ussiri and Lal 2005; Sperow 2006; Amichev et al. 2008; Shrestha and Lal 2010; Tripathi et al.2014, 2016; Das and Maiti 2016.

In India opencast coal mining has substantially increased with the use of contemporary technologies to meet the need for energy. As a result, there will be loss of top soil containing SOC (Severson and Gough 1983; Harris et al. 1993).

The initial removal of the top soil from the mine site results in loss of SOC. Additional losses happen during storage in stockpiles and in the process of reclamation during mine closure. The loss of SOC may adversely affect the soil's water-holding capacity, fertility and overall quality (Stahl et al. 2003).

In general, it is recommended that the topsoil containing the greatest quantity of SOC be removed and stored separately throughout the mining operation. The overburden (OB), consisting of sub-soil and rocks deposited above the mineral bearing zone, is excavated and dumped outside the quarry. It is a good practice to backfill the entire quarry depth with the OB from the dumps and then relay the topsoil on it. Usually this is not done; as a result, mine dump consists of a mixture of topsoil and overburden. Therefore, the soil quality in OB dumps areas, in comparison to the soil in the adjacent areas that are not affected by mining, completely changes. In most cases huge quantity of waste material is left as external dumps on surface near the mines. Some of these dumps are more than twenty years old and are left without any soil treatment and ultimately gets reclaimed naturally. New vegetation cover and good management practices can restore lost C from the atmosphere which will help to improve soil quality and restore SOC (Lal and Bruce 1999; Lal 2000). Vegetation growth and carbon stock accumulation are conspicuously influenced by soil that has been reclaimed from mines. Reclaimed mine soil mostly consists of high proportion of rock fragments, and low proportion of soil forming matters, water holding capacity, humus, available nitrogen and available phosphorous (Maiti 2013).

The nature of soil, humus content and the type of decaying leaves causes variations in SOC concentration. The average SOC (4.27%) is higher as a result of accumulation of coal-carbon fraction or blending of recent-carbon and coal-carbon (Ussiri and Lal 2008). Coal mine soil contains carbon fractions derived from modern and fossilised plants, detritus materials, coal, and inorganic carbonates (Maharaj et al. 2007). Several chrono-sequence investigations have documented the accumulation of carbon in reclaimed mine soil (Akala and Lal 2000; Maharaj et al. 2007; Shrestha and Lal 2010; Mukhopadhyay et al. 2013), that is controlled by the type of substrate, the climate, and the tree species.

The objectives of this research are (i) understanding LULC change over 20 years (1999-2019) due to expansion of mining in Raniganj coalfield area, (ii) identifying the dump sites based on spectral properties, and (iii) calculating the accumulation of SOC in naturally reclaimed OB dump soil in chronosequence (one year, three years, five years, ten years, fifteen years, and twenty years) at two depth profiles and compare them with the SOC of the adjoining wasteland site.

Materials and methods

Study area

Fig. 1 Map showing the research area. Red boundary indicates mine leasehold and yellow circle indicates research area.

Satellite data processing

To investigate the spatial and temporal changes of various LULC for 20-year of mining expansion (1999-2019), two satellite data namely Landsat TM 5 and ESA Sentinel 2B MSI data of 1999 and 2019 (Table 1) were downloaded as GeoTiff product from the Earth Explorer website (http://eartheexplorer.usgs.gov/) for identification of mine lease area, OB dumps, agricultural land, wasteland, tree cover, settlements, barren land and water bodies within the leasehold area and the 10 km buffer zone around the mine site. The data were then geo-referenced (UTM-Zone 45N; WGS-84 datum) using QGIS 3.8 software. Digital image pre- and post-processing techniques and LULC analysis have been elaborately discussed in Dhar et al., (2019).

Table 1 Detailed specification of satellites

Name of Satellite	**Month and Year**	**Path/Row**	**Bands**	**Spatial Resolution**
Landsat 5 Sensor - Thematic Mapper	March 1999	139/044	Visible: Bands 3,2,1 NIR: Band 4 SWIR: Band 7 TIR: Band 6	30 m × 30m
ESA Sentinel 2B Sensor – MSI	March 2019	**Tile No:** T45QWG	Bands 1,2,3,3N, 4, 5, 6, 7, 8, 8A, 9, 10,11, 12* *Bands 5,6,7 are Vegetation Red Edge bands No thermal bands available	10 m × 10m

Identification of naturally reclaimed overburdens using the Overburden Identification Index (OII)

The LU/LC cover in our study area gives us an idea about the presence of different land cover types present in 1999 and as well as in 2019 but do not reveal much about the naturally reclaimed overburden dumps that are formed in and around the mining lease area. Using the spectral properties of the high-resolution Sentinel 2B imagery it is possible to separate the overburden dumps from the rest of the mining lease area using the simple yet efficiently developed Overburden Identification Index (OII). The OII is based on the theory that if the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Built-up Index (NDBI) values for a specific mining area are calculated, as well as the Land Surface Emissivity (LSE), then overburden dumps can be identified by excluding pixels with a certain threshold value from the output raster. Therefore, if the surface reflectance values based on wavelength range of these minerals are excluded from the resultant raster, then it is possible to isolate the pixels associated with the overburden dumps compared to the rest of the mine area. Initially, geo-corrected Google Earth images are chosen along with ground survey data to identify overburden dumps for both the years. They are superimposed over the OII raster to understand the accurate locations where the classified OB dumps are found. It is important to note that NDVI, NDBI and OII rasters are based on NIR (near infrared band), MIR (mid infrared band) and SWIR (short wave infrared band) respectively.

Thus, the product obtained gives the OII.

a) Calculation of the NDVI (Dhar et al., 2019)

$$\text{NDVI} = \left(\frac{NIR-R}{NIR+R}\right) \text{-------------------} \mathbf{(1)}$$

NDVI values range between -1 (lowest NIR reflectance) and 1 (highest NIR reflectance)

b) Calculation of the NDBI (Zha et al. 2003)

$$NDBI = \left(\frac{MIR-NIR}{MIR+NIR}\right) \text{----------------------} \mathbf{(2)}$$

NDBI values range between -1 (lowest MIR reflectance) and 1 (highest MIR reflectance)

c) Summation of spectral bands of NDBI and NDVI raster.

d) Then, the OII can be expressed as

$$OII = \left(\frac{NDBI+NDVI}{LSE}\right) + (\rho_{s1} + \rho_{s2}) \text{----------------------} \mathbf{(3)}$$

Where, ρ_{s1} = Surface reflectance value ofthe OB dump material at NIR wavelength range

ρ_{s2}= Surface reflectance value of OB dump material at SWIR wavelength range (http://speclab.cr.usgs.gov/spectral-lib.html, accessed on 5th March, 2022).

LSE = Land Surface Emissivity, values are based on NDVI and ranges between 0.2 and 0.5 and are chosen for surfaces which are neither soil like or most likely can have the presence of vegetation.

OII thus obtained can identify mine overburdens from a lease area and it is to be mentioned that the index can apply to a mine area only and not for areas where there is no natural land reclamation in wastelands due to mining activity.

Spectral Angle Mapper for estimation of spectral similarities

The Spectral Angle Mapper (SAM) calculates the spectral angles of a sample spectra of n-dimensional bands with a reference spectra in a n-dimensional space. The basis for this classification is that the least spectral angle deviation observed between the two spectras suggest that two spectras are similar and belong to the same class. Higher the angle deviation, greater is the chance for exclusion of a spectra not to be under the classification. The concept of SAM algorithm is given in Figure 2

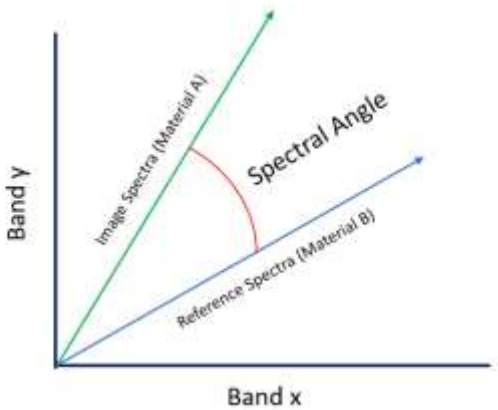

Fig. 2 Spectral angle mapper (SAM) concept

Jawed et al. 2018 conducted a study ondump constituents and concluded that usually overdumps of the Raniganj field area mostly comprises alternating layers of shale and sandstone rocks.As per the calculations obtained by OII, the addition of spectral reflectance values for shale rock helps to distinguish between unknown and known dumps. To understand the spectral similarities of the overburden dumps, the SAM studyiscarried out for the material constituents of the dump. This isdone using the material identification algorithm present within ENVI 5.3 software. Pansharpened images areprocessed using the necessary atmospheric and geometric corrections and the spectral characterstics of the dumps areextracted. The obtained spectral characterstics arecorrelated with available spectral libraries in USGS (https://crustal.usgs.gov/speclab; accessed on 5th March, 2022).

Soil Sampling and Analysis

Six soil samples were obtained from naturally reclaimed OB dumps using a soil corer from two particular soil depths: 0 to 15 cm and 15 to 30 cm, according to a chronosequence of one year, three years, five years, ten years, fifteen years, and twenty years from the time of dumping of the overburden. Soil samples were also collected from an adjoining wasteland without any mining activities. After removing the litter from each sampling location, three samples were collected from metal quadrate of 50 cm × 50 cm dimensions for each depth interval. The samples were carefully packed in air tight bags and transported to the laboratory for physical analysis. The three samples for each depth interval were then mixed using coning and quartering method to get one composite soil sample. After air drying for seven days, the samples were pulverised with a mortar and pestle. The samples were then passed through a <2mm sieve to separate the finer non-soil particles like plant root, small stones, to obtain a soil sample with a similar type of particle size. These sieved soil samples were then tested for SOC as described in Nelson and Sommers (1996). In this method 0.25(N) potassium dichromate (K2Cr2O7) was added to about 5gm of sieved soil sample along with concentrated sulphuric acid (H2SO4) that will oxidize the SOC completely with the release of carbon dioxide (CO2) gas.

$$3\,[CH_2O] + 16H^+ + Cr_2O^{2-}{}_7 = 4Cr^{3+} + 3CO_2 + 10H_2O$$

The excess dichromate was then titrated back with ferrous ammonium sulphate (FAS) or Mohr's salt $[(NH_4)_2Fe\,(SO_4)_2.6H_2O]$ using ferroin indicator. Initially the strength of the FAS solution is determined by a blank set up where the titration was performed according to the above-mentioned procedure only without taking the soil. Next, FAS was determined using the soil. SOC was determined using the following equation:

$$SOC\,(\%) = \frac{3 \times \text{strength of FAS} \times (B-T) \times 100}{W \times 1000} \quad \text{------}(4)$$

where, B = volume of FAS required in blank set up.
T = volume of FAS required in test set up.
W= weight of the soil sample taken.

SOC is expressed in percentage that can be converted into kg ha-1 assuming that 1 ha of land can hold about 2.6 x 106 gm of soil. By this conversion the amount of SOC can be expressed in Mg ha-1 (1Mg = 106gm). According to IPCC (2006) recommendations, the quantity of carbon sequestered (megagram C per hectare) is determined by multiplying the biomass with 0.5. The C sequestered is then converted to CO2 by multiplying it with 3.67 (Das and Maiti, 2016). The soil SOC data obtained from the OB dump sites at different depths are compared with that of the wasteland soil.

Results and discussion

LULC Change Analysis

Figures 3 - 4, and Table 2 depict the spatial distribution of LULC in Sonepur-Bazari for 1999 and 2019. A perusal of the Table 2 shows that there has been a decrease in tree cover from 1999 to 2019 by 9.49 km2. Agricultural lands do not suffer much of the change as the buffer area is not under much anthropogenic disturbance. So far as the mining area is concerned, the mine area has increased by about 11.76 km2 in twenty years and is clearly evident in Figure 4. Mining area has increased rapidly during this period by diminishing the tree cover, agricultural land, and water bodies. Due to natural reclamation and increasing OB dumps, the area of wasteland has increased from 19.37 km2 to 20.55 km2 between 1999 and 2019. The area of settlement increased from 3.39 % in 1999 to 5.02 % in 2019 due to growth of houses holds, road network, etc as a result of mining activity (Figs. 3 and 4; Table 2). Due to change in the river course, some of the area occupied by the river has also decreased i.e., about 2.21 km2. It is interesting to know that among the eight LULC classes, the class that has undergone maximum change in area is the water-bodies with a sharp decrease in the area by 11.68 km2. This is possibly due to increased mining activities which led to filling of these waterbodies.

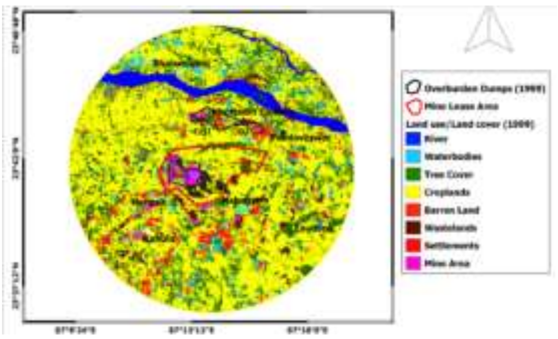

Fig. 3 Spatial distribution of LULC changes during 1999

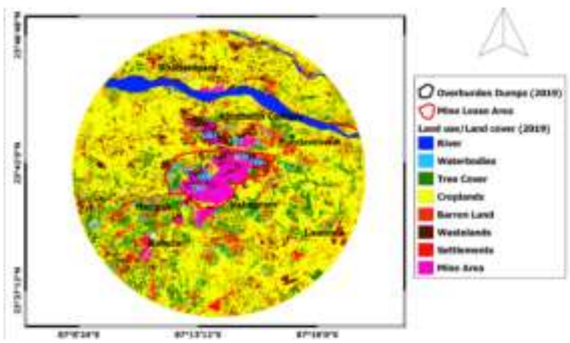

Fig. 4 Spatial distribution of LULC changes during 2019

The same reason may be applicable for the barren lands showing an increase of about 4.0 %. Overall, the entire region has undergone a change of 54.76 km2 (17.5% of the total area). The change conversion table is given in Table 3. A perusal of the table indicates that about 2.55 km2 of the mine area has changed to various LULC types. Among all of the possible changes, about 1.45 km2 has converted to vegetation cover and 0.31 km2 to wastelands. The mines have expanded from 1999 to 2019 by a total area of 13.34 km2out of which 3.64 km2 remains unchanged. About 1.5 km2 of waterbodies are converted to mine areas suggesting the impact on the natural environment by the mining activities. About 14.13 km2 of agricultural land has converted to settlements suggesting the rapid urbanization due to the expansion of the mining area.

Table 2 LULC change between 1999 and 2019

Class	**1999 (km^2)**	**Area in %**	**2019 (km^2)**	**Area in %**	**Change Area (1999-2019)**	**Change %**
Tree Cover	51.35	16.41	41.86	13.37	-9.49	-3.03
Agricultural Land	194.61	62.18	190.61	60.90	-4.00	-1.28
Mine Area	3.77	1.20	15.53	4.96	11.76	3.76
Wasteland	19.37	6.19	20.55	6.57	1.18	0.38
Barren Land	3.36	1.07	12.7	4.06	9.34	2.98
River	13.97	4.46	11.76	3.76	-2.21	-0.71
Waterbodies	15.96	5.10	4.28	1.37	-11.68	-3.73
Settlement	10.61	3.39	15.71	5.02	5.10	1.63
Total	**313**	**100.00**	**313**	**100.00**	**54.76**	**17.5**

Table 3 LULC conversion between 1999 and 2019

	LULC 2019 (Area in km^2)							
LULC 1999	**Tree Cover**	**Agriculture Land**	**Mine Area**	**Settlement**	**Wasteland**	**Barren Land**	**Water bodies**	**River**
Tree Cover	0.00	29.04	0.97	0.98	1.39	0.98	0.22	0.28
Agriculture Land	16.99	0.00	7.9	14.13	14.53	8.45	1.03	0.35
Mine Area	0.52	0.93	0.00	0.3	0.28	0.03	0.28	0.54
Settlement	0.35	0.08	0.05	0.00	0.11	0.32	0.44	0.04
Wasteland	1.31	12.26	3.3	1.66	0.00	1.41	0.39	0.08
Barren Land	0.2	1.07	0.36	0.42	0.59	0.00	0.06	0.09
Waterbodies	3.99	7.58	0.76	0.34	0.38	0.27	0.00	0.04
River	0.02	1.18	0.05	0.05	0.71	0.44	0.05	0.00

Analysis of the Overburden Dumps

Based on the spectral signatures of the mine overburden dumps, the OII provides a deeper insight into the condition of the dumps within the mine lease area. The accumulation of SOC in these overburdens can be assessed accordingly using the OII. The OII raster values are obtained both for 1999 and 2019. The OII raster maps (Figures 5 and 6) indicate that there is a change in landuse pattern as evident from the distribution of OB dumps which also suggest that there has been a significant growth in the expansion of the mining area. A perusal of Figure 5 suggests that the OII value ranges between 0.50 and 1.25 in the year 1999. Values >0.5 have greater probability of being classified as OB dumps which are identified in the figure as light-yellow patches. Values < 0.5 do not fall under OB dumps and thereby are excluded from the analysis. Figure 6 depicts the distribution of OB dumps in 2019. The OII values ranges from 0.5 to 1.00 and values >0.5 have higher probability of being classified as OB dumps identified in the figure by yellow patches. The spatial distribution of the yellow patches has considerably increased from 1999 to 2019 suggesting the expansion of the mining area. Also, from Figures 5 and 6, it is well observed that few portions of the OB dumps which are present in 1999 are not visible in 2019 suggesting that these dumps have been reclaimed. It is also observed from Figure 5 that in few areas where the OII values are zero as identified by Google Earth from 2019 imagery are not classified as OB dumps. Thus, it can be said that OII values greater than >0.5 in a mine area indicate OB dumps.

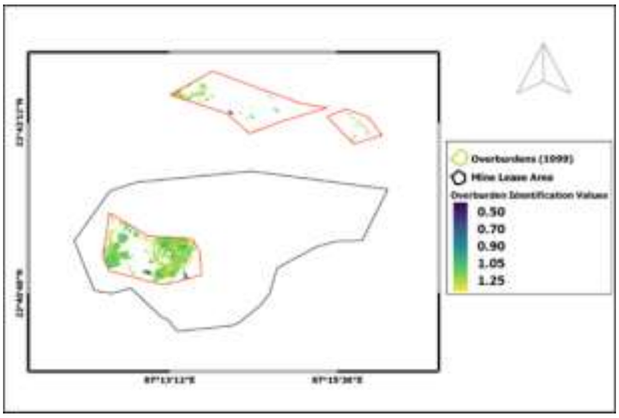

Fig. 5 Locations of overburden dumps based on OII values of 1999. Values > 0.5 are areas where the probability of finding OB dumps is greatest and values < 0.5 indicates least chances of finding OB dumps.

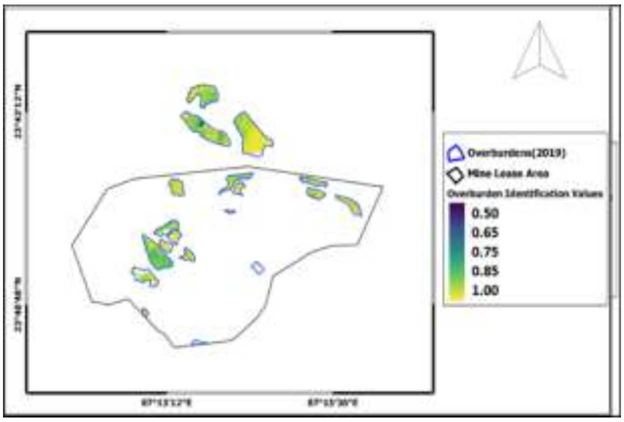

Fig. 6 Locations of overburden dumps based on OII values of 2019. Values > 0.5are areas where the probability of finding OB dumps is greatest and values < 0.5 indicates least chances of finding OB dumps.

Spectral Similarity Assessment of Overburden Dumps

Random samples of reflectance spectra from the satellite imagery are obtained and the SAM algorithm is run through the material identification window in ENVI 5.3. Figure 7 shows the reflectance plots of various materials (arenaceous shale, phosphatic shale, fossiliferous limestone and arkosic sandstone) present in the dumps along with the reflectance spectra obtained from the USGS Library. The variation in curve shows the distribution pattern over short-near-infra red-short wave infrared wavelengths. The reference reflectance values from the USGS library range between 0.30 and 0.50 whereas the reflectance values for the overburdens show a range between 0.22 and 0.47. It is to be noted that the average of two separate range of reflectance values (0.3 -0.5 and 0.22 - 0.47) obtained are being added to the OII raster calculation formula for the output raster that results in the generation of OII and highlights the OB dumps. The spectral angles between the identified materials through the SAM algorithm and that of the image spectra are given in Table 4. Materials having spectral angle between 0.10 and 0.15 (arenaceous shale, phosphatic shale, fossiliferous limestone, arkosic sandstone) are considered to have the highest similarity with that of the overburden dumps identified by the OII as the angular difference between image spectra and reference spectra is least. The increase in spectral angle value beyond 0.15 suggests that materials like micaceous red sandstone, siltstone, black shale are not similar to those present in the overburden dumps because of the wide angular difference between image spectra and reference spectra. Gradually the increase in the spectral angle value>0.20 suggests that the materials are completely dissimilar in nature to that of the overburden dumps as the difference between the spectral angles is the greatest.

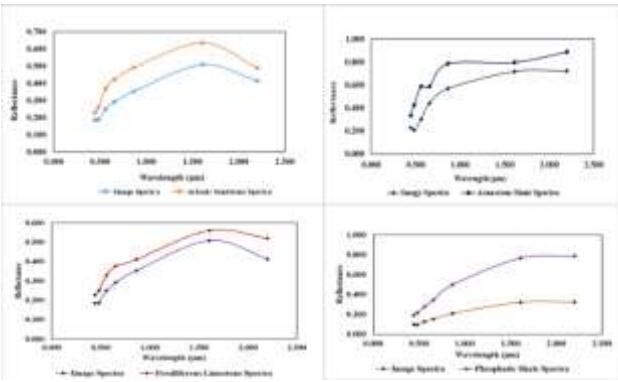

Fig. 7 Spectral reflectance plots showing reflectance values of reference spectra (USGS) along with image spectra for various materials as identified using the SAM algorithm

Table 4. Spectral angle values as obtained from SAM based material identification module

Signature Name	Spectral Angle	Spectral Angle Range
Shale (Arenaceous)	0.1022	0.10 – 0.15
Fossiliferous Limestone	0.1049	
Shale (Phosphatic)	0.1125	
Arkosic Sandstone	0.1299	
Sandstone (Micaceous Red)	0.1525	0.15 – 0.20
Carbonaceous Shale	0.1831	
Siltstone	0.1901	
Black Shale	0.1954	
Shale (Calcareous)	0.2039	>0.20
Ferruginous Sandstone	0.2043	
Glauconitic Sandstone	0.2095	
Sandstone (Micaceous Red)	0.2127	
Illite-bearing Shale	0.2195	
Carbonaceous Shale	0.2444	

Source: USGS Spectral Library v7 **(**https://crustal.usgs.gov/speclab)

Soil Organic Carbon (SOC) sequestration

The SOC content in the study area has increased with time in the waste dumps for 0-15 cm and 15-30 cm depths (Table 6; Fig.8) but decline marginally with depth (Table 7). The SOC content of soil of newly formed OB dumps or recent dumps at <15 cm depth is 9.1 megagram per hectare (Mg ha-1) or 16.7 Mg CO2 ha-1 whereas at the same depth of a 20-year-old OB dump it is 21.6 Mg ha-1 (39.64 Mg CO2 ha-1) (Table 4). For soil samples at depth between 15 and 30 cm SOC has increased from 8.3 to 19 Mg ha-1 (15.23 to 34.86 Mg CO2 ha-1) (Table 6). Total SOC content increases as the dumps get older due to natural restoration process. Tripathi et al. (2014) reported that a 10-year old reclaimed mine-spoil site at Alkusha-Gopalpur in Raniganj coalfield of India shows total accumulation of carbon to the tune of 22.9 megagram C per hectare whereas in a 19-yr old reclaimed soil of Singrauli mine, Madhya Pradesh, India the accumulated carbon was 41.73 megagram C per hectare (+18.83 megagram C per hectare higher than the former). Carbon content of 'reclaimed forest and grassland soils' (0-30 cm depth) of Ohio, USA is 37- 45 megagram C per hectare and 47–79 megagram C per hectare after 21 and 25 years respectively (Akala and Lal 2000, 2001).

In a restored mining soil ecosystem that supports grass and forests the rate of accumulation of carbon varies from 0.1 to 3.1 megagram C per hectare per year and 0.7 to 4 megagram C per hectare per year respectively (Shrestha and Lal 2006; Akala and Lal 2001). Higher average C accumulation of soils for different forest types have been reported by Post and Kwon (2000). In tropical and temperate forests, the upper 30 cm of soil accumulates carbon at a rate of 0.34 megagrams per hectare per year, but permanent grasslands accumulate carbon at a rate of 0.74 megagrams per hectare per year.

In older dumps, where natural restoration is in process, the upper horizon of the dump primarily consists of non-decomposed organic material and partially decomposed soil organic matter. At upper depths (0-15 cm), soil is dark showing SOC buildup. Soil below upper horizon (15-30 cm) is light colored with interspersed roots of naturally originating plants. The soil below 30 cm contains rock fragments with limited roots. The amount of SOC in the adjoining wasteland site is 17.7 megagram C per hectare (32.48 megagram CO2 per hectare) and 17.2 megagram C per hectare (31.56 megagram CO2 per hectare) at depths < 15 and 15-30 cm respectively (Table 7). Therefore, SOC content of the OB dump becomes equal to or greater than that of wasteland only after 10 years (Figure8) which indicates that the OB dumps take> 10 years to be naturally reclaimed.

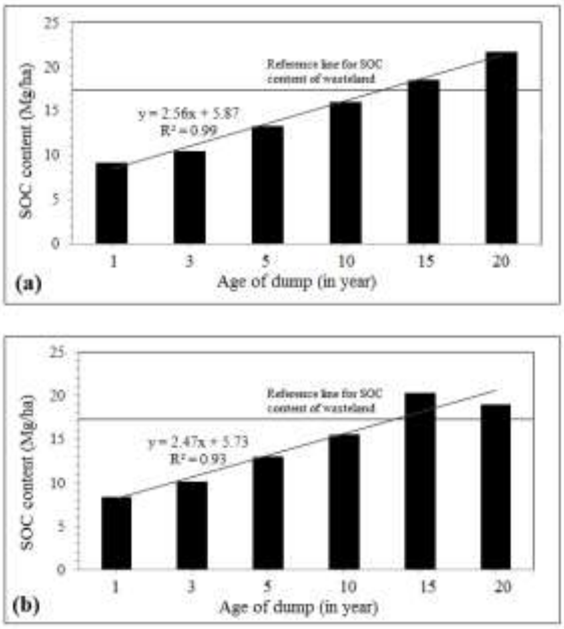

Fig. 8 Temporal changes in total SOC content of dumps and backfilled areas for (a) 0-15cm and (b) 15-30 cm depth.

Table 6 SOC content in Mg ha^{-1} in dumps and backfilled areas with ages and depth of sampling

Depth of sampling (cm)	Sample No	Ages of dumps and backfilled areas	SOC content	
			Mg ha^{-1}	MgCO$_2$ ha^{-1}
0-15	1	1	9.1	16.70
	2	3	10.4	19.08
	3	5	13.3	24.41
	4	10	16	29.36
	5	15	18.5	33.95
	6	20	21.6	39.64
15-30	1	1	8.3	15.23
	2	3	10.14	18.61
	3	5	13	23.86
	4	10	15.6	28.63
	5	15	20.3	37.25
	6	20	19	34.87

Table 7 SOC content in Mg ha^{-1} in wasteland with ages and depth of sampling

Sample no	Depth of sampling (cm)	SOC content	
		Mg ha^{-1}	MgCO$_2$ ha^{-1}
1	0-15	17.7	32.48
2	15-30	17.2	31.56

A significant factor in determining quality of mine soil is soil carbon content. Storing that carbon in recovered soil is acknowledged as a potential strategy for reducing greenhouse gas emission (Lal 2004). The amount of SOC builds up expeditiously during the initial 20 years following reclamation and then subsequently accumulates slowly between 20 and 30 years and come to an equilibrium condition in 100–150 years (Akla and Lal, 2000, 2001). The accumulation of carbon stock will take place mostly in the biomass component compared to mine soil component.

Reclamation through construction of cover plantation and nutrient-saving manure application techniques is preferable to simple plantation because it results in re-establishment of the ecosystem in the deteriorated mine site, pollution reduction and carbon sequestration, and thus tackling the problem of climate change and global warming. Such reclamation technique in opencast mining area may be adopted for resource constrained nation like India and the carbon sequestered may be utilized to generate carbon credits that may be a valuable source of revenue to meet the needs of the growing population.

Conclusions

The present work deals with the change of LULC due to increase of mining activities in an opencast mine in the eastern part of Raniganj Coalfield, chronosequence study of SOC content in the naturally reclaimed mine dump soil compared with the adjoining wasteland and identification of overburden dump using multispectral imagery ESA Sentinel 2B MSI data of 1999 and 2019 and newly developed Overburden Identification Index. Mining activity has increased manifold since 1999 with the increase of settlement and decrease of tree cover. Amongst the eight LULC classes the area of the waterbodies has drastically decreased. About 14 km2 agricultural land has been converted to settlements indicating urban growth. A new approach has been developed to identify mine overburden dump based on the spectral signatures of different rock types obtained from Landsat TM 5 and matching them with USGS spectral library. Materials (arenaceous shale, phosphatic shale, fossiliferous limestone, arkosic sandstone) with spectral angle between 0.10 and 0.15 have the highest similarity with that of the overburden dumps. The amount of SOC content has increased in the OB dumps at depths <15 and 15-30 cm with time but with depth the amount has slightly decreased. The OB dump areas are often left for natural restoration without any scientific restoration planning. On a decadal scale, natural restoration improves the SOC content and thus increases the rate of carbon sequestration relative to neighbouring wasteland. Therefore, a scientific OB dump management program such as, tree plantation and application of manure may be planned to enhance the soil building process and increase the SOC and sequestration of carbon.

Acknowledgement:

The authors thank the Director, Indian Institute of Social Welfare and Business Management for providing necessary infrastructure and encouragement for the research work.

COI or 'Conflict of Interest': "The authors declared that they have no conflict of interest".

References:

Adams, R.M. (1999). Agriculture and global climate change: A Review of Impacts to U.S. Agricultural Resources, The Pew Center on Global Climate Change, Arlington, V.A.

Akala, V.A., &Lal, R. (2000). Potential of mine land reclamation for soil organic carbon sequestration in Ohio. *Land Degradation and Development,11(3)*, 289–297.

Akala, V.A., &Lal, R. (2001). Soil organic carbon pools and sequestration rates in reclaimed minesoils in Ohio. *Journal of Environment Qualilty, 30(6)*,2098–2104.

Amichev, B.Y., Burger, J.A., &Rodrigue, J.A. (2008). Carbon sequestration by forests and soils on mined land in the Midwestern and Appalachian coalfields of the US. *Forest Ecological Management, 256(11),* 1949–1959.

Barnett, T.P., &Schlesinger, M.E., (1987). Detecting changes in global climate induced by greenhouse gases.*Journal of Geophysical Research, 92,*14772-14780.

Bishwal, R. M., Sen, P., &Jawed, M. (2018). A laboratory study on estimation of shear strength and compaction properties of overburden dump material in Indian coal mines. *Journal of the Geological Society of India, 92(3)*, 363-367.

Brown, S., Lugo, EAriele., &Iverson, R Louis. (1992). Processes and lands for sequestering carbon in the tropical forest landscape. *Water Air Soil Pollution,64*, 139-155.

Campbell JB (2007) Introduction to remote sensing, 4th edn. The Builford press, New York, p 625.

Chavez, P.S. (1996). Image-based atmospheric corrections-revisited and improved. *Photogrammetric Engineering and Remote Sensing, 62(9),* 1025–1035.

Congedo, L. (2013). Semi-automatic classification plugin for QGIS. Rome: Sapienza University.

Das, R., &Maiti, S.K. (2016). Importance of Carbon Fractionation for the estimation of Carbon sequestration in Reclaimed Coalmine soils–a case study from Jharia Coalfields, Jharkhand, India. *Ecological Engineering, 90*,135–140.

Davidson, I. & Ackerman, L. (1993) Changes in Soil Carbon Inventories Following Cultivation of Previously Untilled Soils. Biogeochemistry, 20, 161-193.

Dhar Basu,R., Chakraborty,S., Chattopadhyay,R., &Sikdar,P.K. (2019). Impact of Land-Use/Land-Cover Change on Land Surface Temperature Using Satellite Data: A Case Study of Rajarhat Block, North 24-Parganas District, West Bengal. *Journal of Indian Society of Remote Sensing,47(2),* 331–348.

Fernando, J., & Nag, D. (2003). A study of internal overburden dump design and stability analysis for Hazelwood Power Mine, Latrobe Valley, Victoria, Australia". *Application of Computers and Operations Research in the Minerals Industries,* South African Institute of Mining and Metallurgy, 267-274.

Hansen, J., Lacis, A., Rind, D., Russell, G., Stone, P, Fung, I., Ruedy, R.,& Lerner, J. (1984). Climate sensitivity: Analysis of feedback mechanisms. In *Climate Processes and Climate Sensitivity*. J.E. Hansen and T. Takahashi, Eds., AGU Geophysical Monograph 29, Maurice Ewing 5. *American Geophysical Union,5*,130-163.

Harris, J.A., Birch, P., & Short, K.C. (1993). The impact of storage of soils during opencast mining on the microbial community: A strategist theory interpretation. *Restoration Ecology, 1,* 88–100.

Houghton, J.T. (1996). The Science of Climate Change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Climate change 1995: Cambridge University Press, Cambridge, U.K.

IPCC (2000). Special report on land use, land use change, and forestry, summary for policy makers. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

IPCC (2006). IPCC Guidelines for national greenhouse gas inventories. Intergovernmental Panel on Climate Change, NGGIP Publications, IGES, Japan

Jime´nez-Mun˜oz J.C., Sobrino, J.A., Skokovic,´D., Mattar, C., & Cristo´bal, J. (2014). Land surface temperature retrieval methods from Landsat-8 thermal infrared sensor data. *IEEE Geoscience and Remote Sensing Letters*, *11(10)*,1840–1843.

Kruse, F., Lefkoff, A., Boardman, J., Heidebrecht, K., Shapiro, A.,&Barloon, P. (1993). The spectral image processing system (SIPS)—Interactive visualization and analysis of imaging spectrometer data. *Remote Sensing of Environment*, *44(2–3)*, 145–163.

Lal R (2000) Soil aggregation and C sequestration in Global climate change and tropical ecosystems, CRC Press, Inc., Boca Raton, FL 317-329.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science204*, 1623–1627.

Lal, R., &Bruce, J.P. (1999). The potential of world cropland soils to sequester C and mitigate the greenhouse effect. *Environment Science Policy, 2*,177–185

Lindzen, R.S. (1994). On the scientific basis for global warming scenarios.*Environmental Pollutants, 83*, 125-134

Maharaj, S., Barton, C.D., Karathanasis, T.A., Rowe, H.D., Rimmer, S.M. (2007) Distinguishing'' new'' from'' old'' organic carbon inreclaimed coal mine sites using thermogravimetry: II. Field validation. *Soil Science*,*172(4)*,302–312.

Maiti, S.K. (2013).Ecorestoration of the coalmine degraded lands. Springer, New York.

Moran, M.S, Jackson RD, Slater PN, &Teillet, P.M. (1992). Evaluation of simplified procedures for retrieval of land surface reflectance factors from satellite sensor output. *Remote Sensing of Environment*,*41(2–3)*, 169–184.

Mukhopadhyay, S., Maiti, S.K., Masto, R.E. (2013). Use of reclaimed mine soil index (RMSI) for screening of tree species for reclamation of coal mine degraded land. Ecological Engineering,*57*,133–142

Nelson, D.W., Sommers, L.E. (1996). Total carbon, organic carbon, and organic matter. Methods of soil analysis, Part 3(3):961–1010

Post, W.M., &Kwon, K.C. (2000). Soil carbon sequestration and landuse change: processes and potential. *Global Change Biology*,*6(3)*, 317–328.

Santer, B.D., Taylor, K.E., Wigley, T.M.L, Penner, J.E., Jones, P.D., &Cubasch, U. (1995). Towards the detection and attribution of an anthropogenic effect on climate. PCMDI Report 21, Lawrence Livermore National Laboratory, Livermore, California.

Schlesinger, W.H. & Bernhardt, E.S. (2013). Biogeochemistry: An Analysis of Global Change. Third Edition.

Severson, R.C.,&Gough, L.P. (1983).Rehabilitation materials from surface coal mines in the western USA. I. Chemical characteristics of spoil and replaced cover soil.*Reclamation and Revegetation Research, 2*,83-102

Shrestha, R.K., &Lal, R. (2006). Ecosystem carbon budgeting and soil carbon sequestration in reclaimed mine soil. *Environment International, 32*,781–796

Shrestha, R.K., &Lal, R. (2010). Carbon and nitrogen pools in reclaimed land under forest and pasture ecosystems in Ohio, USA. *Geoderma*, *157(3)*, 196–205.

Singh, A.N., &Singh, J.S. (1999). Biomass net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region.*Forest Ecology Management, 119(1)*, 195–207.

Sobrino, J.A., Jime´nez-Mun˜oz, J.C., &Paolini, L. (2004). Land surface temperature retrieval from LANDSAT TM 5. *Remote Sensing of Environment, 90(4)*, 434–440.

Sperow, M. (2006). Carbon sequestration potential in reclaimed mine sites in seven East- Central states. *Journal of Environmental Quality*, *35(4)*, 1428–1438

Stahl, Peter D., Anderson, Jonathan D., Ingram. Lachlan J., Schuman, Gerald E., &Mummey, Danie L. (2003). Accumulation of organic carbon in reclaimed coal mine soils of Wyoming. *Proceedings of the American Society of Mining and Reclamation*, 1206-1215. https://doi.org/10.21000/JASMR03011206.

Tripathi, N., Singh, R.S., & Hills, C.D. (2016). Soil carbon development in rejuvenated Indian coal mine spoil. *Ecological Engineering*, *90*, 482–490.

Tripathi, N., Singh, R.S, &Nathanail, C.P. (2014). Mine spoil acts as a sink of carbon dioxide in Indian dry tropical environment. *Science of Total Environment, 468*, 1162–1171.

Ussiri, DAN., Jacinthe, P.A., & Lal, R. (2014). Methods for determination of coal carbon in reclaimed minesoils: a review. *Geoderma*, *214*, 55–167

Ussiri, DAN., & Lal, R. (2008). Method for determining coal carbon in the reclaimed mine soils contaminated with coal. *Soil Science Society of America Journal, 72(1):*231–237.

Van Rossum, G. (2007). Python programming language. In *USENIX Annual Technical Conference*, 31, 36 p.

Zha, Y., GAO, J., & Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM Journal of the Indian Society of Remote Sensing imagery. *International Journal of Remote Sensing*, *24(3)*, 583–594.

Biographies

SURAJIT CHAKRABORTY received the Master Degree in Geological Science from Jadavpur University and doctorate from IIEST, Shibpur. His research interests are Hydrogeology, Remote Sensing and GIS, Carbon Sequestration. He is an Assistant Professor, Department of Environment Management, IISWBM, Kolkata He may be reached at surajitc@iiswbm.edu

ROHIT BASU DHAR received the Master Degree in Environmental Science from Ballygunge Science College, University of Calcutta. His research interests are Remote Sensing and GIS, Biodiversity mapping etc. He is working as a Environmental Health and Safety Officer at MNC. He may be reached at rohitbasu01@gmail.com.

PRADIP K. SIKDAR had his masters and doctorate degree from the University of Calcutta (Geology/Hydrogeology) and University of Newcastle-upon-Tyne, UK (Integrated Coastal Zone Management). Currently as the Professor in the Department of Environment Management, IISWBM, Kolkata he is actively engaged in research and teaching groundwater hydrology and environmental impact assessment. He has over 28 years of experience in project management and implementation, field and research work in groundwater systems including application of computer models in scientific evaluation of hydrogeologic systems, groundwater resources development and protection. He may be reached at p_sikdar@hotmail.com.

SURANJAN SINHA has his masters and doctorate degree in mining engineering from Indian School of Mines, Dhanbad. He is a Former Professor in the Department of Mining Engineering, IIEST, Shibpur. He had almost 35 years of experience in mine plan and design, mine closure, slope stability etc. He may be reached at suranjan1980@gmail.com.