Assessment of Mining Activities in Jharia Coalfield using Remote Sensing

Ph.D. Thesis Synopsis

by

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1. Introduction: Mining in India is a major industrial activity which contributes significantly to the national economy. The overall contribution of mining/mineral sector in terms of GDP is about 2.2 to 2.5% (Annual Report, 2010-11), Ministry of Mines, Government of India). According to the Indian Ministry of Mines, 80% of mining is for coal and the remaining 20% for various metals and other raw materials such as gold, copper, iron, lead, bauxite, zinc and uranium. As a prospering economy, India faces energy security as a growing challenge and the coal production is expected to grow at a compound annual growth rate (CAGR) of around 7% during 2011-12 to 2013-14. The Indian coal market is set to witness great boost in near future because of the rising government initiatives. Mining also has a significant impact on the environment, but the environmental awareness of the global mining industry has become an important issue only in recent years (Lamb, 2000). The three major activities of the mineral resources mining industry are mining, mineral processing, and metallurgical extraction. These produce wastes, thereby causing serious environmental harms (Lottermoser, 2007). Overall environmental impact due to mining depends on number of factors, in particular: the method of mining (opencast/underground) and their magnitude (Bell et al., 2000).

The remote sensing and GIS techniques are extensively used since last few decades specially for mineral exploration. However, these techniques are, at present, also being used for management and monitoring of mining operations mostly by the developed economies (Lamb, 2000). During 'surface mining' activities - extraction of ore along with stripping and dumping of overburden, the land cover and land use of the mine area is continuously changed. Sustainable mining requires constant monitoring of these changes to identify the long-term impacts of mining on environment and land cover to provide essential remedial measures. Remote sensing techniques /earth observation using space based sensors are very powerful tools for obtaining rigorous data over a period of time and hence minimizing the need of time-consuming and costly field measurements.

Effect of mining on surface features and soil cover is to some extent detectable with satellite earth observation data. Opencast mining (OCM) can directly affect the ground surface resulting formation of depression and also heaps created by dumping of waste. The other serious and direct effect is removal of top soil, damage of manmade structures due to blasting, etc. adversely effecting human settlements. In addition, there can be many more such minor influences on the area affected by mining. These direct variables are predictable and caused by the mining operations itself and restricted to the same place and time. In addition, there are many more indirect effects which crop up at a later stage and also can propagate to a larger distance and for example perturbation of surface and ground-water hydrology. Indirect variables may include cumulative effects related to induced changes in the pattern of land use and related effects on soil, air and water and other natural systems.

Quantifying the temporal and spatial patterns of land use/land cover (LULC) change, as well as its consequences for ecological, hydro-climatological, and socioeconomic systems on the earth, is a central focus of land change science (Turner et al., 2003), thus underlining a need for more careful, objective, and quantitative estimation of the trajectory and spatial dimension of mined land conversions. Knowledge of the extent of mining and reclamation is critical to managing or mitigating the potential impacts of surface mining. Remote sensing has been used widely to characterize land cover changes and maps derived from remotely sensed data provide critical inputs for understanding dynamic process.

Jharia Coalfield (JCF) in Jharkhand, India is the only source of prime coking coal in India and is very important for industrial development of the nation (Acharya, 2000). A long history of coal mining for more than 100 years includes land damage and alteration of its original lush green pristine forest cover. Un-systematic mining over a long period of time resulted in severe land degradation, change of original landscape to abandoned quarries, mine dumps, subsided depressions, mine fires, etc., with highly degraded vegetation cover. JCF is probably one of the most popular area for coal mining not only in the country but also at international level due to its typical characteristics and unique status and problems (Kumar et al., 2012). The landscape in the JCF changes continuously due to coal mining activity and associated coal fire, thus changing the land use rapidly (Prakash and Gupta 1998). Several studies on coal fire mapping and land use change have been carried out for the JCF from satellite data (Chatterjee et al. 2007).

A comprehensive study of the JCF using information derived from remotely sensed data would provide critical inputs for understanding for such dynamic events over a large timeline. The present research has been carried out on three scales i.e. mapping changes in land cover for entire extent of the coal field, analyzing the effect of surface mining in the OCM areas and a detailed analysis by integrating elevation information with the changes in land cover to model and predict future scenarios.

2. Scope of Research: The Jharia Coalfield in Jharkhand, India, is the only source of prime coking coal in India and has a reserve of about 5.3 billion tonnes (Acharya, 2000). The only storehouse of prime coking coal in the country, the coalfield has been witnessing mining since 1894 and is probably one of the most densely populated coal mining areas in the world. Mining in this coal field was initially in the hands of private entrepreneurs, who had limited resources and lack of desire for scientific mining. The mining methods comprised of both open cast as well as underground extraction. The open cast mining areas were not back filled, so large void is present in the form of abandoned mining. Extraction of thick seam by caving in past at shallow depth has damaged the ground surface in the form of subsidence and formation of pot holes or cracks reaching up to surface, enhancing the chances of spontaneous heating of coal seams and mine fire. The other factor which damages the land in JCF is opencast mining and overburden dumps.

However, coal is an essential source of energy in meeting the requirements of the existing and growing industries of a nation. Damage to the environment is usually seen as an unavoidable consequence of maintaining national development. Thus it is desirable to optimize and minimize environmental impacts by adopting proper mining techniques. Therefore, it is necessary to have quickly accessible, cost-effective, multi-temporal information regarding the area's environmental status. Remote sensing technology affords a viable means of analyzing the changing conditions at mine sites.

This research is an attempt to understand and quantify the temporal and spatial patterns of LULC, as well as model and predict its consequences. Mapping and monitoring the indicators of opencast coal mining can help immensely for efficient planning and management of mining operations, assessment of impacts on land use, and execution of reclamation measures. A space-borne earth observation technique by integrating elevation information and spatial pattern of LULC change for delineating un-reclaimed, abandoned or closed opencast mines would be extremely useful for monitoring opencast mining operations and for estimating the extent of unattended damage due to opencast mining.

The remote sensing approach would facilitate quantification of land-cover changes in terms of percentage of area affected and rates of change, to assess the nature of changes in terms of impact on natural vegetation, to map the spatial pattern of land-cover change and to predict land-cover distributions in the future.

3. Study area and data used: The JCF is located in the Dhanbad district of Jharkhand state, India; covering an area of 446 km^2. The coalfield is contained within latitudes 23° 38' N to 23°52' N and longitudes 86°08' E to 86°30'E. The JCF is characterized by an undulating topography, with gentle slope towards the eastern part of the area. The average height is 200m above mean sea level. Damodar, which flows from west to east, is the major river in this area.

Rocks belonging to the Gondwana Supergroup from Upper Carboniferous to Lower Cretaceous age, i.e., from 320 to 98 million years old, are exposed. They unconformably overlie older Archaean rocks. In the Gondwana Supergroup of rocks, the Permian Barakar and Raniganj formations have more potential for coal production in comparison to other formations. Most of the coal mines in this area are confined to the Barakar Formation, which consists of coarse to medium grey and white sandstones, shales and coal seams. Raniganj consists of grey and greenish soft feldspathic sandstones, shales and coal seams. Faults are prevalent in this portion of the basin. NE–SW-trending faults are conspicuous in the JCF. Many lamprophyre and dolerite dykes are also exposed in a criss-cross manner. The Raniganj Formation, although coal bearing, has suffered much deformation, thus making mining much more difficult (Saraf *et al.*, 1995).

Data for this study has been collected from different sources. The data have been categorized under the following categories:

1) Time sequential satellite images (IRS I C PAN + LISS III -1997/2001/2002, IRS P6 LISS IV – 2003-2010, IRS Resourcesat-2 LISS IV -2012)

2) Satellite data derived digital elevation models. (SAR interferomtric data of ENVISAT ASAR, 2002- 2010)

3) Survey of India toposheets (73 I /1, I /2, I /5, I /6 at 1: 50,000 scale)

4) Ancilliary data (Geological Map from Geological Survey of India -1997, satellite derived – base map, drainage map, contour map, Ground Control Points, Reference data for Accuracy Assessment, volume of coal production and overburden dumps)

4. Objectives: The primary objective of this study is to provide a data driven tool based on earth observation to identify, assess, predict and manage impacts of mining on surface features. To achieve this major research objective the work has been carried out under the following sub-objectives:

i. Rapid estimation of overburden and excavated material to study the impact of OCM on topography.
ii. Surface mining induced spatio-temporal impact assessment on LULC at varying scales-regional and local.
iii. To construct a predictive model to forecast the trend of LULC change which can be further used for evaluating and monitoring the progress of mining activities in the region.

5. Methodology: Within the framework of this study a methodology for regional mapping of landuse/cover classes is developed, that has been applied and validated on time-series of satellite data covering the Jharia coal fields which are areas with a long history in mining. The methodology also includes post classification change detection and trend analysis using Cellular automata - Markov chain analysis. Summarized workflow is given in Fig.1

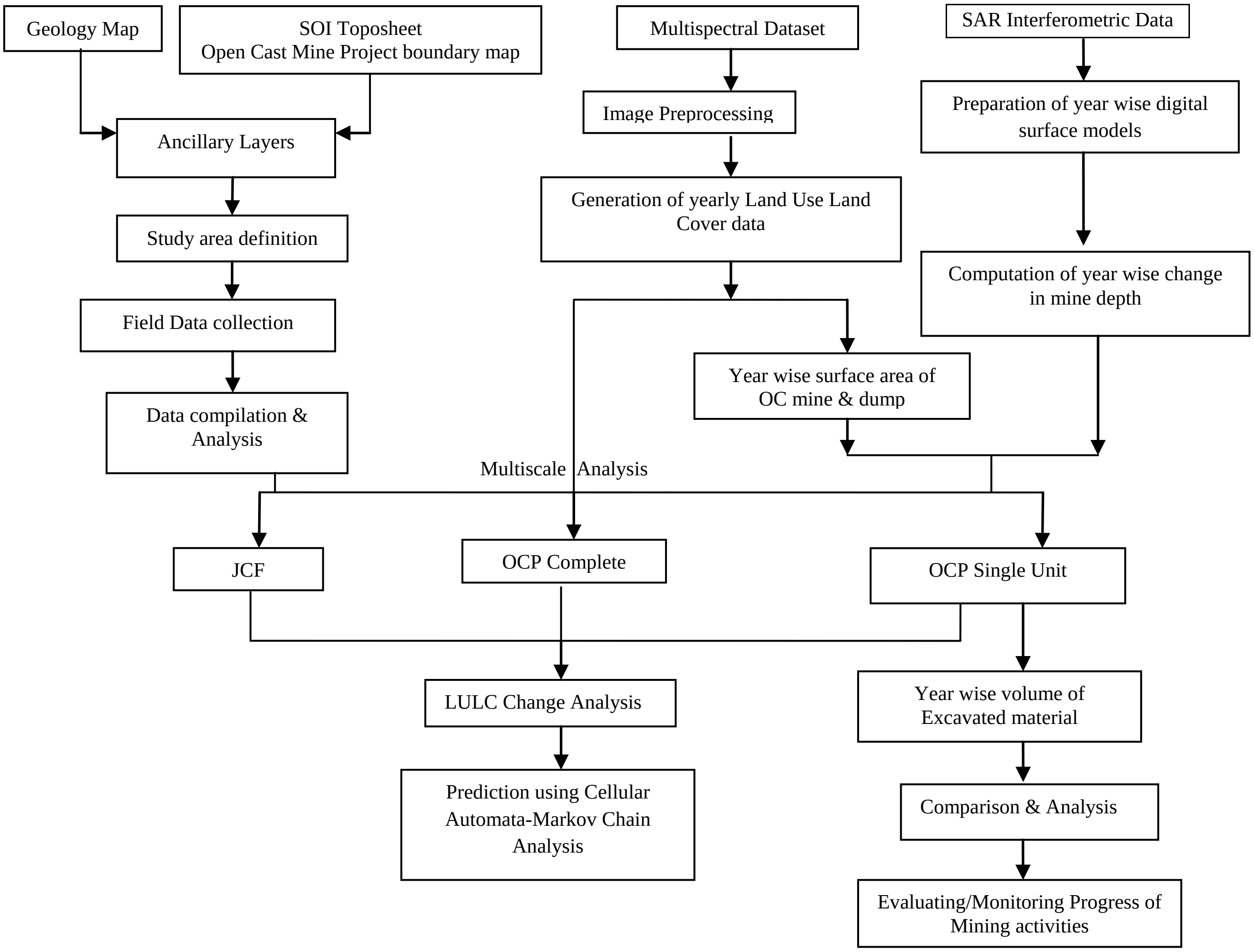

Fig.1. Workflow of the proposed Methodology

a. Ancilliary data preparation/collection: Relevant ancillary data viz; Geological map (after GSI), base map, drainage and contour information from SOI toposheets, surface faults and lineaments (after CMPDI,) and outline map of JCF, Open Cast Project(OCP) area and Lodhna area were prepared.

b. Field data Collection: Ground Control Points using single frequency geodetic global positioning system (GPS) were collected. Data related to coal production and overburden dumps for Lodhna area was procured from the colliery archives. Reference data for post classification accuracy assessment was also collected in.

c. Elevation data extraction: Synthetic Aperture Radar systems record both amplitude and phase of the backscattered echoes. It has been observed that the phase spectrum of an image is more characteristic to the image than its magnitude spectrum (Ghiglia and Pritt, 1998). The phase of a single SAR image is of no practical use (Rocca et al., 1997). On the contrary, if two SAR images from slightly different viewing angles are considered (for interference), their phase difference can be exploited efficiently to generate digital elevation models (DEMs), to monitor terrain changes and to measure minute surface displacements. In SAR interferometry technique, the phases of two SAR images of the same area are made to interfere to generate an interferogram having a number of interference fringes. Each interference fringe corresponds to a phase difference of 2π between the two component SAR images. Yearly SAR interferrometric data from 2002-2010 has been used. Interferometric processing of ERS SAR tandem pair and ENVISAT repeat-pass pair single look complex (SLC) data has been carried out for DEM and coherence map generation of the study area.

d. Feature Identification and Classification: Optical remote sensing images have been selected for the time period ranging between years 1996 till 2012. The spatial resolution was chosen to be 5.8 m and kept fixed for the entire study period. To achieve this resolution pan sharpened LISS III or LISS IV images were utilized. The images were rectified so as to achieve perfect pixel to pixel registration. Using the unified land cover classification scheme developed in a previous study (Chatterjee *et al*., 2007), the multitemporal images were classified using probability based classifier. The image was classified into 8 LULC classes , viz. open cast mine, mine dump, vegetation, agriculture, barren, settlement, sand and water. The classification accuracy was assessed using the common ‘confusion matrix’ method.

e. Estimation of excavated and mining dump area: The areal extent of the open cast mine and mine dump was estimated from the classified output. The difference in elevation in the open cast mine was calculated using difference in digital elevation models of relevant years. Thus the volume of excavated material and mining dump was estimated. These estimates were compared with the ground information for a small open cast mine.

f. Impact Assessment through Change Detection and Prediction: Land Use/ Land Cover change detection was carried out using post classification comparision method. The change detection results were examined in terms of proportion of land-cover classes, change trajectories and spatio-temporal patterns of change. The process of land-cover change was modelled by a Cellular automata-Markov chain method to predict land-cover distributions in the near future. To model a process of land-cover change by a Markov chain, the land-cover distribution at t_2 is calculated from the initial land-cover distribution at t_1 by means of a transition matrix (Jokar *et al*., 2011). The Markov chain can be expressed as: $v_{t2}=M\times v_{t1}$

where v_{t1} is the input land-cover proportion column vector, v_{t2} is the output landcover proportion column vector and M is a $m\times m$ transition matrix for the time interval $Dt=t_2- t_1$. Markov chain analysis ignores the forces and processes that produced the observed patterns. It assumes that the forces that produced the changes will continue to do so in the future. In addition it does not take into account the spatial element. To overcome this limitation and to add the spatial dimension to the model, cellular automata is used in conjunction. In cellular automata, there are cellular entities that independently vary their states, as well as their immediate neighbours, according to predefined transition rules (Lambin and Geist, 2006).

6. Results and Discussion:

a. **Elevation data extraction:** The phase difference are measured in the repeating interval from zero to 2π, where every 2π cycle is equivalent to a Line-of-Sight (LOS) change equal to one-half of the radar wavelength, which is about 28 mm for SAR data collected by ENVISAT ASAR (C-band) sensor. The phase difference data are unwrapped to create and unwrapped interferogram. The phase is then converted into height. A DEM derived from ENVISAT ASAR (C-band) sensor is shown in Fig. 2. The elevation data brought out surface changes in topography due to OCM activities.

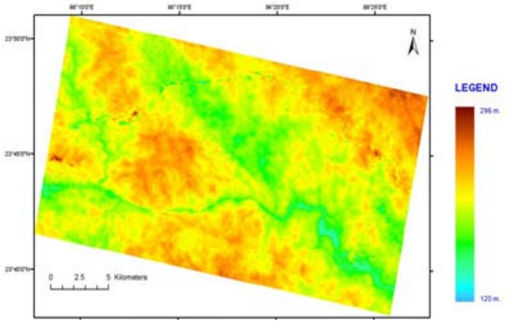

Fig. 2: Digital Elevation Model (DEM) generated from the ENVISAT ASAR (C-band) pair.

b. **Image Classification:** Five successive probability based supervised classifications (1997, 2001, 2005, 2008, 2012) discriminated eight classes viz: open cast mine, mine dump, vegetation, agriculture, barren, settlement, sand and water (Fig.3). The classification accuracy achieved is in the range of 84% to 87%.

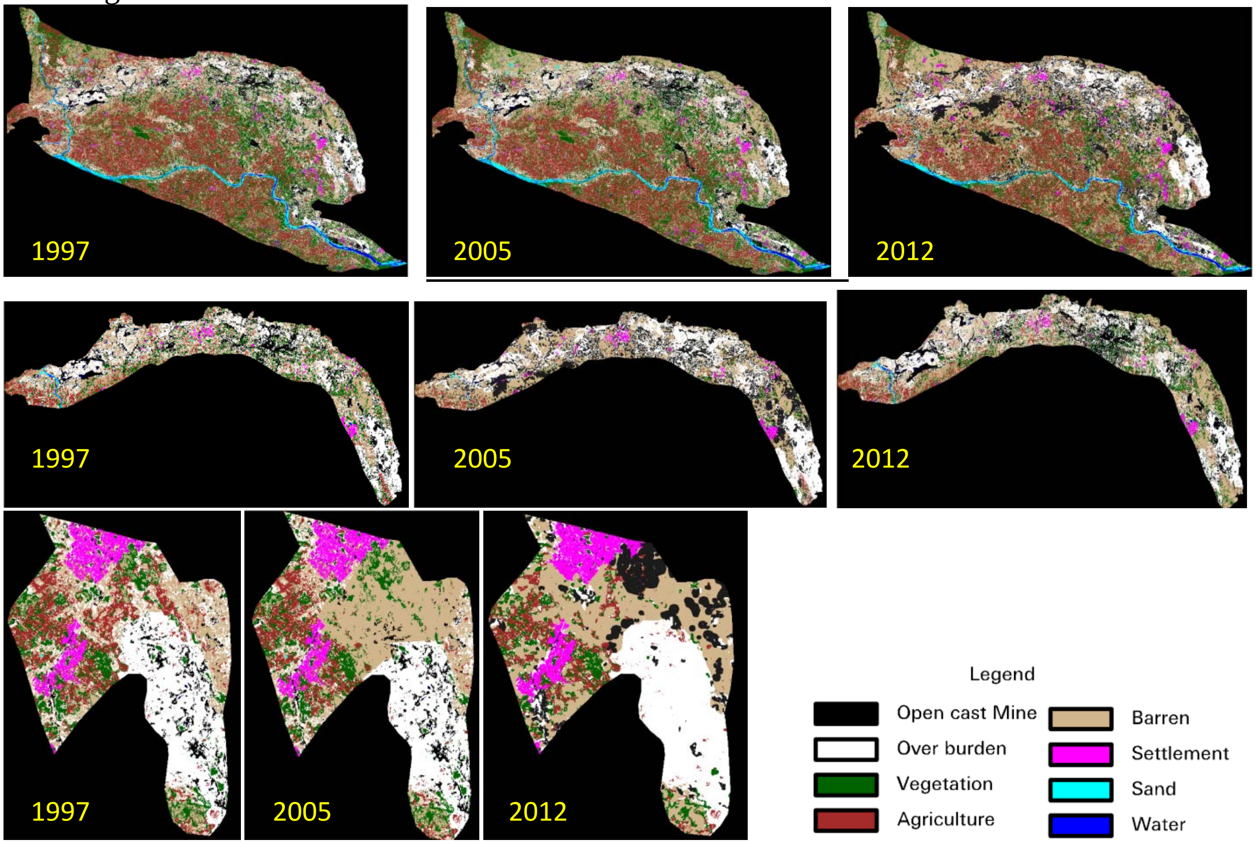

Fig 3: Classified data for 1997, 2005 and 2012

c. **Estimation of excavated and mining dump area:** The image derived volume of total excavated material and mine dump was compared with the actual values obtained from the colliery in Lodna. Fig.4 shows the graphical comparison of the data for the years 2002 - 2010.

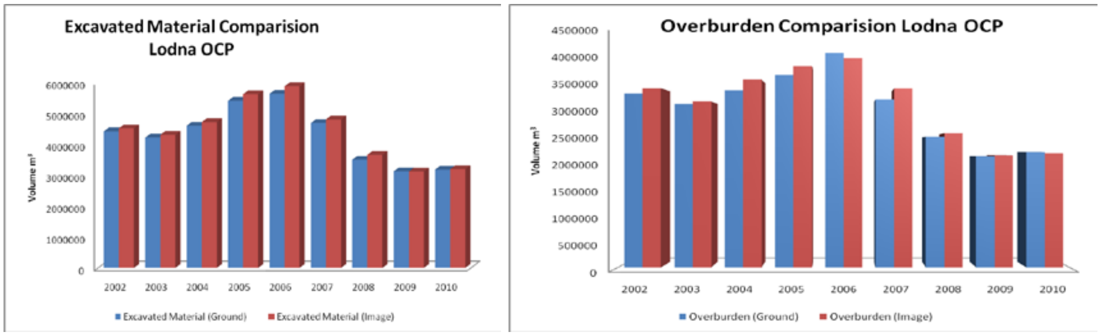

Fig. 4: Image Vs Ground data for total excavation and overburden

d. **Change Detection and Prediction:** Post classification comparison was carried out for assessing LULC changes induced by open cast mining activity in the area. Table 1 shows the temporal area statistics in Jharia coal field area. Similarly area statistics pertaining to open cast mining areas and colliery in Lodna were also extracted separately. The area statistics show the general landuse change pattern.

Table 1: Area Statistics (in Ha.) of Jharia Coal Field, Dhanbad

Class/Year	1997	2001	2005	2008	2012
Open cast Mine	3037.34	3194.36	4208.51	5287.55	5997.21
Over Burden	6997.90	7110.01	7412.67	8114.83	8496.83
Vegetation	9722.10	9670.76	8279.49	7820.39	6556.76
Agriculture	9010.16	8898.39	8570.33	8436.34	8238.14
Barren	10291.91	10883.32	11711.54	13156.52	13243.11
Settlement	468.52	587.17	689.02	751.16	942.13
Sand	850.05	850.05	916.23	925.98	933.18
Water	478.16	478.08	486.46	492.12	522.14
Total area	43656.16	43656.16	43656.28	43655.90	43656.53

Cellular automata-Markov chain hybrid method was utilized for simulating the LULC scenario in the area for year 2016 and 2020. Fig. 5 shows the simulated images. The projection of the future land-cover pattern on the basis of Markov chain shows a continuous trend of increase in mining area, barren land, and built-up area where as vegetation is in continuous decreasing trend.

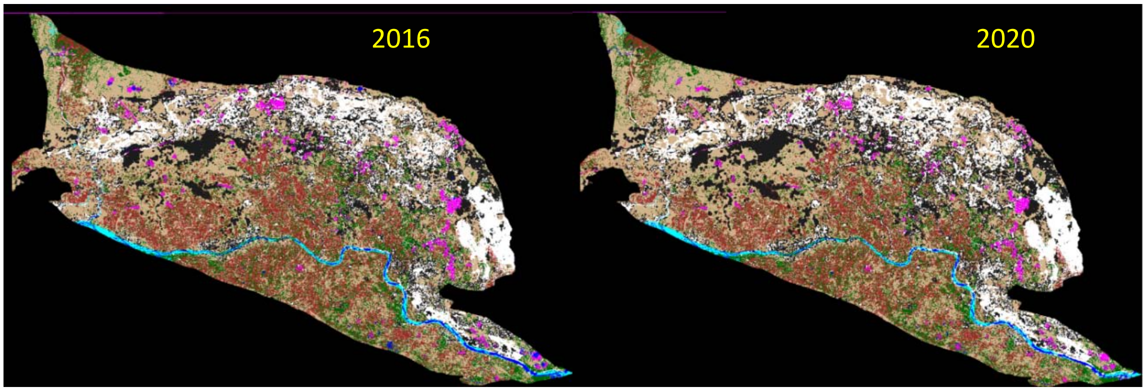

Fig 5: Predicted scenarios for 2016 and 2020

Temporal change trajectories were generated for each class to assess the spatial pattern of change in the area. Temporal trajectory analysis was also conducted with the particular focus on the analysis of unchanged and stable change trajectories, because they generally show the trend of LULC change that is irreversible. Unstable change trajectories, on the other hand, show relatively less significance since they largely contain reversible temporary changes. Fig. 6 depicts change trajectories corresponding to different land use classes.

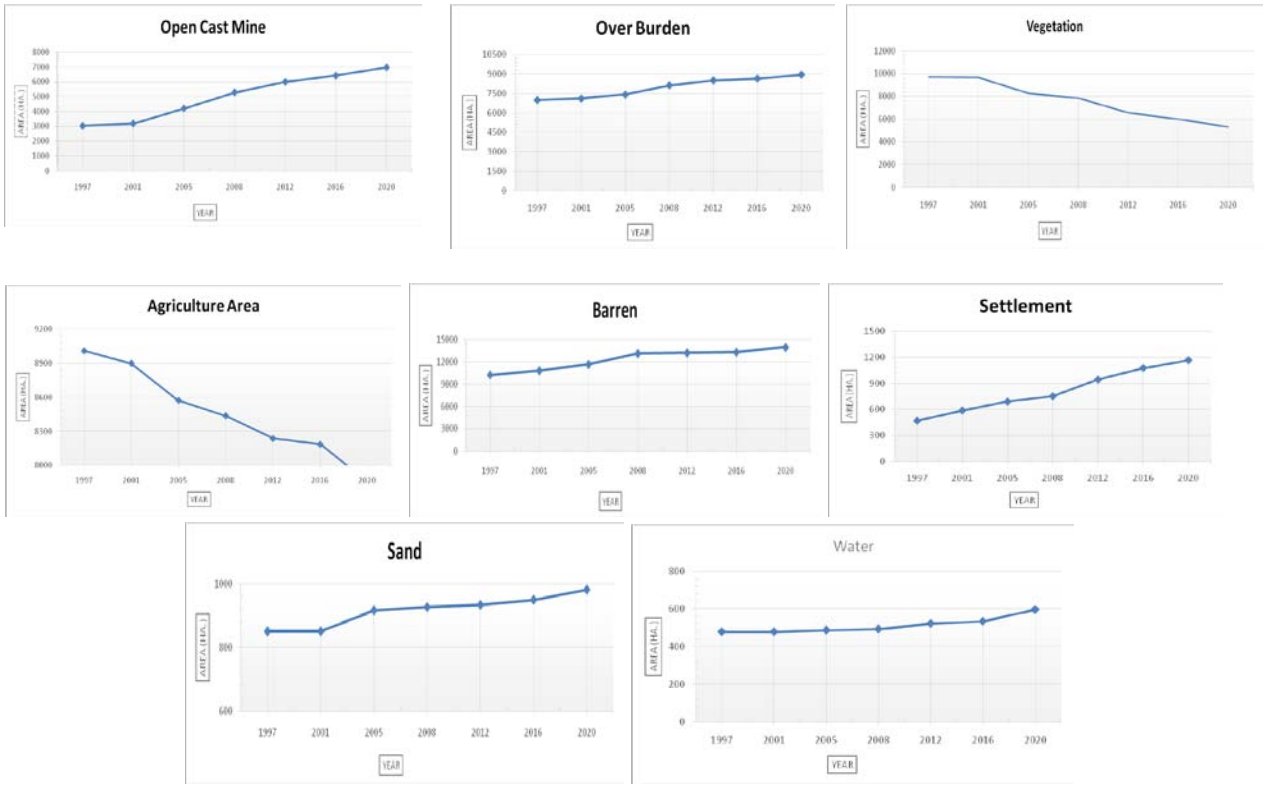

Fig 6: Change trajectories for different land use classes

7. Summarized Conclusion: Remote sensing technology affords a viable means of analyzing the dynamically changing conditions at mine sites at variable scales with sufficient accuracy. The methodology for rapid estimation of overburden and excavated material in open cast mining areas using earth observation data is expected to equip decisions makers with a tool for evaluating and monitoring progress of mining activities. The approach is capable of predicting the most probable sites for development, estimating the likely amount of change as well as allocating the estimated quantity within the study area.

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