Land-use mapping and change detection in a coal mining area—a case study in the Jharia coalfield, India

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Abstract. In an area like the Jharia coalfield (JCF), where extensive and rapid underground and opencast mining is going on continuously, land-use studies are of paramount importance. This paper discusses the remote sensing-GIS techniques used for identification of various land-use classes on satellite imagery and enhanced products and identification of time-sequential changes in land-use patterns.

The various land-use classes, recognised from satellite image data and field surveys, are dense vegetation, sparse vegetation, fire, opencast mining (coal), overburden dump, subsidence and barren wasteland, settlement, transport network, river and water pond. A number of image processing operations have been carried out on remote sensing data for enhancing land-use patterns. It has been found that Landsat TM false colour composites (FCC) of bands 4, 3 and 2; FCC of bands 7, 5 and 3; FCC of bands 5, 4 and 2 and ratio images provide very useful information for land-use mapping. The normalised difference vegetation index (NDVI) images have been used for vegetation studies. Image characters of various land-use classes on black-and-white and enhanced colour products have been tabulated. Land-use maps of selected windows have been prepared and examples given.

Time-sequential surface changes that have occurred in the JCF since 1975 and particularly between November 1990 to November 1994 have been investigated. For change detection analysis, data manipulation in several steps involving preprocessing, processing and colour display have been carried out. Land-use changes have been detected by (a) image differencing, (b) image ratioing, and (c) differencing of NDVI images. It is inferred from the remote sensing images that extensive mining, establishment of communication networks, expansion of settlements, decrease in the vegetation cover etc., have remodelled the face of the JCF.

1. Introduction

The importance of mapping land-use classes and monitoring their changes with time has been widely recognized in the scientific community. Remote sensing and geographical information systems (GIS) are important tools for studying land-use patterns and their dynamics. Land-use changes are invariably associated with mining of natural resources. Studying changes in land-use pattern using remotely-sensed data is based on the comparison of time-sequential data. Change detection using satellite data can allow for timely and consistent estimates of changes in land-use trends over large areas, and has the additional advantage of ease of data capture into a GIS.

1.1. The study area

India’s resources of prime coking coal are concentrated in the Jharia Coalfield (JCF) in Bihar state. This coalfield, located about 250 km NW of Calcutta, is confined
between latitudes 23°38'N and 23°50'N and longitudes 86°07'E and 86°30'E (figure 1). The JCF has been selected as the study area because it has a long and diverse mining history which involves both opencast and underground mining spanning over a century. Unplanned mining of coal in the JCF, particularly commencing in 1920s, has led to severe environmental degradation in and around the area. Occurrence of fires, mining induced subsidences, abandoned mining sites, rehandling of overburden dumps, etc. are continuously changing the land-use pattern in this area.

1.2. Role of remote sensing-GIS in land-use studies
Preparation of the land-use maps by conventional methods is very time consuming and expensive. Moreover, ground surveys may be tedious in some areas. Also, as mentioned earlier, the changing land-use patterns require a frequent updating of the existing land-use maps of the area. Remote sensing provides multi-spectral and multi-temporal synoptic coverages for any area of interest. The satellite data provides a permanent and authentic record of the land-use patterns of a particular area at any given time which can be re-used for verification and re-assessment. Digital format of the satellite data gives it a tremendous flexibility. On the other hand, GIS provides the facility to integrate multi-disciplinary data for dedicated interpretations in an easy and logical way. This integrated approach proves to be time-saving and cost-effective.

1.3. Methodology
The remote sensing GIS based techniques for land-use studies in the JCF include the following two main themes; (1) Identification of various land-use classes on
satellite imagery and enhanced products, and (2) image processing and enhancement for identifying the time-sequential changes in land-use patterns.

For this study, the data used include:

1. Remote sensing data
   (a) Landsat MSS data of 19 November, 1975,
   (b) Landsat TM data of 28 November, 1990,
   (c) Landsat TM data of 7 November, 1994,
   (d) IRS LISS-II data of 21 September, 1990.
2. Survey of India toposheets at 1:50,000 scale
3. Selected topographic maps at 1:4,000 scale
4. Geological map at 1:25,000 scale (published by CMPDIL-RI-II, Dhanbad)
5. Structural map at 1:25,000 scale (published by CMPDIL-RI-II, Dhanbad)
6. Land-Use map at 1:50,000 scale (published by Orissa Remote Sensing Centre)
7. Subsidence map at 1:50,000 scale (published by BCCL, Dhanbad)
8. Fire map at 1:50,000 scale (published by BCCL, Dhanbad)
9. Mining-area map at 1:32,000 scale (published by CIL)
10. Published reports and maps from various libraries and mining-area offices
11. Field checking during which observations have been made regarding the geology, structure, coal-mining, overburden dumps, subidences, ponds, land-use patterns, vegetation, changes in human settlements, coal fires etc. Ground temperature measurements in several profiles have also been made.

The methodology adopted for land-use studies in the JCF has involved preprocessing and processing of the data.

1. Preprocessing has involved digitisation of Survey of India toposheets at 1:50,000 scale to serve as the base map, inputting the digital remote sensing data into the GIS data-base, digitisation of all other relevant maps and data viz. geological, structural, topographic, fire-area, land-use etc., registration and georeferencing of all data sets.
2. Processing has involved application of various GIS functions and advanced digital image processing (DIP) techniques including contrast manipulation, edge enhancement, colour compositing, density-slicing, colour-coding, ratio image generation, principal component analysis, IHS transformation, overlay and logical operations etc. Interpretations have been made from these processed images.

2. Land-use mapping

Land-use mapping in the JCF based on remote sensing data has been attempted in the past by some workers. Ghosh and Ghosh (1991) based their studies on visual interpretation of photographic products. Chatterjee et al. (1994) attempted a supervised classification of remote sensing data. However, use of photo-products does not offer the flexibility for feature enhancement as does the digital data. In an area like JCF which has a complex mining history and involves different land-use classes with very similar or overlapping signatures, supervised classification has its limitations. Therefore, in this study a mixed approach has been followed. The digital data have first been enhanced and then interpreted using elements of photo-interpretation and geotechnical elements.

The various land-use classes, recognised in the JCF, on the basis of satellite image data and field surveys are
<table>
<thead>
<tr>
<th>S.no.</th>
<th>Land-use classes</th>
<th>Blue</th>
<th>Green</th>
<th>Red</th>
<th>NIR</th>
<th>SWIR</th>
<th>TIR</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dense vegetation</td>
<td>Medium dark</td>
<td>Bright</td>
<td>Very dark</td>
<td>Very bright</td>
<td>Bright</td>
<td>Not suitable</td>
<td>Includes forests and new plantation by field organizations. Fine to medium texture.</td>
</tr>
<tr>
<td>2.</td>
<td>Sparse vegetation</td>
<td>Medium</td>
<td>Medium bright</td>
<td>Dark</td>
<td>Bright</td>
<td>Moderately bright</td>
<td>Not suitable</td>
<td>Includes agriculture areas and scantily vegetated areas texture medium to rough.</td>
</tr>
<tr>
<td>3.</td>
<td>Fire</td>
<td>Not suitable</td>
<td>Not suitable</td>
<td>Not suitable</td>
<td>Not suitable</td>
<td>Bright for very high temperature fires</td>
<td>Bright for subsurface fire-areas</td>
<td>Higher the temperature of the areas, brighter the tones in shorter wavelength bands.</td>
</tr>
<tr>
<td>6.</td>
<td>Subsidence and barren wasteland</td>
<td>Moderately bright</td>
<td>Moderately bright to bright</td>
<td>Bright</td>
<td>Variable brightness (depends on moisture content)</td>
<td>Bright</td>
<td>Not suitable</td>
<td>Fine to medium fine texture. Distinction from overburden dumps can be made on the basis of size, texture, drainage and associations.</td>
</tr>
<tr>
<td></td>
<td>Land use</td>
<td>Bright/Top</td>
<td>Light grey</td>
<td>Medium (grey) Dark</td>
<td>Medium (grey) Dark and prominent</td>
<td>Medium to dark</td>
<td>Not suitable</td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>----------------------------------</td>
<td>------------</td>
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<td>----------------------------------</td>
<td>----------------</td>
<td>--------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>7</td>
<td>Settlement</td>
<td>Bright</td>
<td>Light grey</td>
<td>Medium (grey) Dark</td>
<td>Medium to dark</td>
<td>Not suitable</td>
<td>Linear and looped shape.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Transport network River</td>
<td>Medium (grey)</td>
<td>Medium (grey) Dark</td>
<td>Medium (grey) Dark and prominent</td>
<td>Medium to dark</td>
<td>Not suitable</td>
<td>Linear and looped shape.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>River</td>
<td>Bright for shallow, dark for deep water</td>
<td>Medium (grey) Dark</td>
<td>Medium (grey) Dark and prominent</td>
<td>Medium to dark</td>
<td>Not suitable</td>
<td>Sinuous shape. Associated with point bars.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Water pond</td>
<td>Bright</td>
<td>Moderately bright</td>
<td>Dark</td>
<td>Dark</td>
<td>Dark</td>
<td>Small natural ponds are irregular. Man- made pods have sharp borders.</td>
<td></td>
</tr>
</tbody>
</table>
1. Dense vegetation
2. Sparse vegetation
3. Fire
4. Opencast mining (coal)
5. Overburden dump
6. Subsidence and barren wasteland
7. Settlement
8. Transport network
9. River
10. Water pond

Their recognition characteristics on black-and-white images and processed image data products are tabulated in table 1 and table 2, respectively.

2.1. Identification of land-use classes on black-and-white images

Figure 2 shows linearly stretched edge enhanced black-and-white images of a part of the JCF as seen in TM bands 3 and 4. Most of the land-use classes can be identified on these bands. To discriminate all the land-use classes, combined use of multi-spectral images and their enhanced products is necessary.

1. Dense vegetation: This class includes forest areas and areas where large-scale plantation schemes have been implemented. Dense vegetation appears medium dark in the blue band image due to absorption by leaf pigments, relatively brighter in the green band image due to the small green reflection peak, very dark in red band image due to absorption by chlorophyll pigment present in the green leaves and very bright in the near-infrared band, the brightness being governed by the internal structure of the leaf. In SWIR-I, this class again appears bright due to reflectance by the leaf constituents and in SWIR-II it appears dark due to absorption by the water content in the leaf. Densely vegetated areas are found in patches of varying spatial extent. In some parts the boundaries are irregular, while in other parts they are sharp. Texture is fine to medium on the remote sensing images.

2. Sparse vegetation: This class includes agricultural areas and rather scantily vegetated areas. The spectral response in such areas depends on the soil/bedrock as well as the vegetation. The texture is medium to rough. Tones on images are relatively moderate for the sparsely vegetated areas. This class is found as small patches and is abundant in the JCF.

3. Fire: The fire-areas (both surface and subsurface fires) are marked by high radiant temperatures (Saraf et al. 1995). Subsurface fires can be delineated on TM-6 and surface fires that on TM-7 and TM-5 bands. On all other bands, viz, TM-1–TM-4, the fire areas appear dark. The fires are found in association with coal bands and dumps, scattered throughout the sickle-shaped JCF. Their frequency and number are relatively higher in the eastern part than in the other parts of the coalfield.

4. Opencast mining (coal): Opencast mining areas appear dark in visible and NIR band images. They can be recognised on black-and-white images as coal bands get exposed on the surface due to mining. Coal bands appear as black linear-curved linear features, following the general strike of the rocks in the area. The associated coal dumps appear as black irregular adjoining patches. The mining area is generally devoid of all vegetation and shows medium to rough texture.

5. Overburden dump: Overburden dumps have spectral signatures quite similar to
<table>
<thead>
<tr>
<th>S.no.</th>
<th>Land-use classes</th>
<th>FCC 432</th>
<th>FCC 542</th>
<th>FCC 753</th>
<th>NDVI</th>
<th>FCC PC123</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dense vegetation</td>
<td>Dark red</td>
<td>Green</td>
<td>Dark green</td>
<td>Very bright in black-and-white image</td>
<td>Dark blues</td>
<td>Includes forests and new plantations.</td>
</tr>
<tr>
<td>2.</td>
<td>Sparse vegetation</td>
<td>Faint red</td>
<td>Greenish yellow</td>
<td>Faint green</td>
<td>Not suitable</td>
<td>Light blue</td>
<td>Includes agricultural land and scantily vegetated areas.</td>
</tr>
<tr>
<td>3.</td>
<td>Fire</td>
<td>Not suitable</td>
<td>Very high temperature surface fires</td>
<td>Yellow and red (surface fires)</td>
<td>Not suitable</td>
<td>Not suitable</td>
<td>Small yet important class. Found scattered in the JCF. Can be identified on TM6, TM5 and TM7.</td>
</tr>
<tr>
<td>5.</td>
<td>Overburden dump</td>
<td>Whitish grey</td>
<td>Greyish</td>
<td>Off white to Greyish</td>
<td>Grey</td>
<td>Green</td>
<td>Small and associated with opencast mining.</td>
</tr>
<tr>
<td>6.</td>
<td>Subsidence and barren wasteland</td>
<td>Dirty white</td>
<td>White to pinkish</td>
<td>White to pinkish</td>
<td>Dark in black-and-white image</td>
<td>Variable</td>
<td>Occupies major area in the JCF. Texture fine to medium.</td>
</tr>
<tr>
<td>7.</td>
<td>Settlement</td>
<td>Bluish-grey to steel-grey</td>
<td>Shades of blue</td>
<td>Shades of mauve</td>
<td>Not suitable</td>
<td>Not suitable</td>
<td>Shows typical checkered pattern.</td>
</tr>
<tr>
<td>8.</td>
<td>Transport network River</td>
<td>Black</td>
<td>Dark and prominent</td>
<td>Dark grey and distinct</td>
<td>Dark</td>
<td>Not suitable</td>
<td>Linear and sometimes looped shape.</td>
</tr>
<tr>
<td>9.</td>
<td></td>
<td>Black</td>
<td>Bluish to bluish black</td>
<td>Bluish black drainage pattern very prominent</td>
<td>Dark</td>
<td>Green</td>
<td>Shows typical sinuous shape. Associated with point bars.</td>
</tr>
<tr>
<td>10.</td>
<td>Water pond</td>
<td>Black</td>
<td>Blue</td>
<td>Blue</td>
<td>Dark</td>
<td>Green</td>
<td>Natural ponds are irregular. Man-made ponds have sharp borders.</td>
</tr>
</tbody>
</table>
wasteland (discussed below), the difference between the two being in their size and association. Overburden dumps are often smaller than barren wasteland and are associated with opencast mining areas. They show textures more rough than wasteland. They are generally devoid of vegetation and drainage. However, vegetation may appear on very old dumps making them appear as natural land.

6. Subsidence and barren wasteland: The subsidence phenomenon in the JCF is very old. Some subsidences are so old that vegetation has grown and settlements have come up on the subsided areas. As a result, the old subsidence areas appear merged with the general topography of the area and thus it is difficult to identify them on images. In some subsidence areas water may accumulate and then these may be discerned on multispectral images due to higher surface moisture. Nevertheless, sufficient field evidences, particularly associated mining history, are essential to demarcate these areas with reasonable certainty. Thus, in the present study, subsidence areas and barren wasteland have been clubbed under one land-use class. Possibly, inputs from synthetic aperture radar (SAR) interferometric data could help to differentiate between these two classes. Barren land reflects strongly in all multi-spectral bands. Depending on the type of rock and/or soil, minor changes in the brightness tones occur in different multi-spectral bands. As far as distribution is concerned, this class occupies a major area in the JCF. It shows fine to medium-fine texture. Distinction from overburden dumps is based on size, texture, drainage and association.

7. Settlement: This class comprises of towns, villages and industrial areas which include several man-made features. Generally, settlements appear light grey on visible and NIR images and dark grey on SWIR band images. These areas bear a typically checkered pattern due to house clustering separated by roads.

8. Transport network: These structures appear medium grey on blue and green band images, dark grey on red, NIR and SWIR band images. They are aligned linearly and sometimes in a looped form. A large network of roads and railway track
is spread across the JCF. Transport network is visible on all spectral band images, but is specially distinct on the NIR image.

9. River: Water exhibits different characters depending upon its silt content and depth of the water body. Clear deep water bodies are dark in all spectral bands. Shallow water appears bright on blue band image and the tone of the water body becomes successively darker on green and red band images. In NIR and SWIR all water bodies appear black. The river appears dark on TIR images due to the relatively lower temperatures of the water. The Damodar River and its various tributaries are easily recognised on the images due to their typically sinuous shape (at places linear) and associated point bars.

10. Water pond: Shallow water ponds appear bright on the blue band image, light grey on green band image, medium grey on red band image and dark in NIR and SWIR images. These are often small in extent. The natural ponds have irregular shapes and generally occur in barren areas. The man-made tanks for water storage have sharp borders and are found near the mining areas.

2.2. Image enhancement for identifying land-use classes

Digital image processing (DIP) is an important step in feature extraction from digital data (Jensen 1986, Mather 1987, Sabins 1987, Gupta 1991). Various types of digital operations carried out on the satellite data and enhanced products generated for identifying land-use classes are discussed briefly. The criteria for identifying the land-use classes on enhanced image products are summarised in table 2.

1. Edge enhancement: Individual spectral bands have been edge enhanced to emphasize high frequency variations and subsequently these enhanced bands have been used to generate colour composites. Edge enhanced NIR and SWIR images are particularly useful for studying the drainage network in the area. Other features like transport network, boundaries of water bodies, faults etc. become very distinct on edge enhanced images.

2. Colour composites: FCCs of various types have been generated. Among the many FCCs generated, three are of special interest; (a) standard FCC (b) FCC of TM bands 5, 4 and 2 (RGB), (c) FCC of TM bands 7, 5 and 3 (RGB).

On the standard FCC, vegetated areas appear in shades of red and sparsely vegetated areas in faint red. Water bodies and coal bands and dumps appear black and are indistinguishable from each other. Transport network also appears black. Barren wastelands and overburden dumps appear in shades of dirty white and grey. However, overburden dumps generally occur in the vicinity of mining areas. Surface settlements appear in shades of grey (bluish-grey, steel grey etc.) and show typical checkered pattern associated with built-up areas.

On the FCC of TM bands 5, 4 and 2 (RGB) (figure 3), vegetation appears in shades of green and yellow. This FCC is particularly suitable for discriminating coal bodies from water bodies. Coal bands and coal dumps (visible in opencast mining areas) appear brown to brownish-black. Water bodies, on the other hand, appear in deep blue to bluish-black shades. Barren land and overburden dumps appear greyish-pink and to differentiate between the two, the association of these features has to be considered. Settlements show up in shades of blue. Transport network, drainage pattern and lineaments are also distinct.

On the FCC of TM bands 7, 5 and 3 (RGB), vegetation appears in shades of green. Dense vegetation shows relatively darker shades of green, but distinguishing
the classes of vegetation is rather difficult. Coal bands and dumps appear characteristically dark brown to brownish-black. Water bodies (ponds, tanks etc.) appear blue, whereas rivers appear blue to bluish-black. Drainage pattern is very prominent. Overburden dumps and barren land appear in off-white to greyish shades. Surface fire-areas stand out as either bright yellow with adjacent red pixels or as bright red pixels (Prakash et al. 1997). These fire zones are only a few pixels in extent. Settlements appear distinctly in shades of mauve. Transport network and lineaments are also very distinct.

3. Density-slicing Colour coding: Density-slicing colour coding has been used to enhance display and facilitate interpretation. Single band images such as TM6 have been used for zoning surface thermal anomalies, vegetation variation etc. Processed images such as vegetation index images have also been subjected to density-slicing colour coding.

4. Principal Component Analysis: Principal Component (PC) images have been generated using VNIR-SWIR bands of TM data. PC-1, PC-2 and PC-3 images have then been coded in red, green and blue, respectively. On this PC FCC, general differences in vegetation and landform are seen (Jha and Unni 1994). Vegetation appears in shades of blue and magenta. However, it is found that in the JCF area, ratio images have given better results and therefore the ratio images have been more extensively used than the PC images.

5. Ratio images: The normalised difference vegetation index (NDVI) image generated using the formula NDVI = \((\text{TM-4} - \text{TM-3})/\text{(TM-4 + TM-3)}\), has proved to be the most useful. On the black-and-white NDVI image the vegetated areas appear in bright tones. The NDVI image has been further colour enhanced.

As an example the area south of Jharia has been selected for illustration. The land-use map of this area (figure 4) has been generated based on the interpretation from black-and-white images and enhanced digital data products.
3. Land-use change detection

Studying changes in land-use pattern using remotely-sensed data is based on the comparison of the time-sequential data. Differences in surface phenomenon over time can be determined and evaluated visually or using digital techniques (Garg et al. 1988, SAC 1990). Automated change detection using satellite data can allow for timely and consistent estimates of changes in land-use trends over large areas, and has the additional advantage of ease of data capture into a geographical information system (GIS).

For land-use change detection in the JCF, the remote sensing data have been acquired for November, i.e., the early winter period, as in summers the soil moisture is very low and monsoon time data is also not suitable. Field data collection for ground truth checking has also been done in winter time. Ancillary data, such as maps pertaining to topography, geology, structure, fire, land-use etc. have been used. Further, studies for change detection have involved geometrical correction of the remote sensing image data with reference to ground control points on topographic maps and registration of ancillary data sets. Finally, normalisation of the image data has been done to facilitate mutual comparison.
Figure 5. Schematic representation of data flow for land-use change detection studies in the JCF.

The change detection work has been done with data from Landsat MSS (1975), Landsat TM (1990 and 1994) and IRS LISS (1990). Schematic representation of data flow for part of the study is shown in figure 5. This has involved three main steps, viz., preprocessing, image processing and colour display.

3.1. Preprocessing: registration and data normalisation

3.1.1. Registration

Multi-temporal dataset analysis requires accurate geometric co-registration (Singh 1986). According to Milne (1988), two images must be registered within an accuracy of one pixel or less, since registration errors could potentially be interpreted as land-cover change. In the present study, to compare the satellite data acquired from different sensors, an image to map registration (where the digitised toposheet on 1:50 000 scale has served as the master map) was performed. To compare the multi-temporal data acquired by the same sensor, an image to image registration is preferred. As images from the same sensors have similar geometry, the transformation (registration) is carried out with minimal changes in the original image.

Registration brings all data to the same scale and geometry. For this, ground control points (GCPs) have been independently selected for all the images. Affine transformation followed by resampling using nearest neighbour interpolation has been performed to co-register the data sets. Care has been taken to keep the root
mean square error (RMSE) well below one in all cases, to achieve the desired subpixel level accuracy.

3.1.2. Normalisation

Normalisation is a broad term which covers one or more of several processes designed to bring multi-date data at par such that a direct comparison of the grey values gives an indication of actual or ‘true’ change (Jensen 1986). In practice, the images acquired on different dates ‘appear’ different due to several reasons, the main being variations in reflectance due to different sun elevation angles, changes in atmospheric conditions, variation in gain setting of various sensors and land cover changes.

In the present study, TM data of 28 November 1990 and 17 November 1994 are found to be particularly well suited for detecting changes in land-use as the study area is monotonously flat and the relative variation in solar elevation angle is not significant for these images. Both images belong to the same season (winter) and so the atmospheric, phenological and seasonal factors can be assumed to be quite comparable. Mansor et al. (1994) carried out normalisation in the JCF and used Lowtran 7 code for atmospheric corrections. They reported no major influence of atmospheric conditions on the image. Therefore, the atmospheric correction procedure was not performed in this study.

However, a simple comparison between 1990 and 1994 TM data shows relative differences in the range of DN-values. Therefore, statistical normalisation of the two data sets is considered necessary. The procedure adopted for statistical normalisation is as follows:

1. The 1994 image was considered as the reference image (image-I), whereas the 1990 image was considered as the image to be normalised (image-II).
2. Mean vector (M) and standard deviation (Sd) of both images were calculated.
3. Image-II was transformed on a pixel-by-pixel basis (overlay operation) using the following conversion algorithm.

\[
DN_{\text{nor-II}} = \left( \frac{Sd_{\text{im-I}}^{1/2} Sd_{\text{im-II}}^{-1/2}}{M_{\text{im-II}}} \right) (DN_{\text{im-II}} - M_{\text{im-II}}) + M_{\text{im-I}}
\]  

(1)

where, 
- \(DN_{\text{nor-II}}\) = New normalised DN of image-II
- \(DN_{\text{im-II}}\) = Original DN of the image-II
- \(Sd_{\text{im-I}}\) = Standard deviation (dispersion matrix) of image-I
- \(Sd_{\text{im-II}}\) = Standard deviation (dispersion matrix) of image-II
- \(M_{\text{im-II}}\) = Mean vector of image-II
- \(M_{\text{im-I}}\) = Mean vector of image-I

The effect of normalisation is shown in figure 6.

3.2. Image processing

The preprocessed images (i.e., co-registered normalised images) have been subjected to techniques of image differencing, image ratioing and differencing of NDVI images, for detecting land-use changes.

A difference image has been generated by subtracting TM-4 (1990) image from the TM-4 (1994) image. The resultant difference image is Gaussian in nature, with no-change pixels centred around the mean while the tail regions on either side contain information about the changed areas. This image gives a very good picture
Figure 6. Effect of statistical normalisation. Image histograms and data statistics are shown (a) TM 1994 image data, (b) TM 1990 image data (co-registered with TM 1994), (c) TM 1990 (co-registered and normalised).
of the changes that have occurred in the JCF. Converse difference image (TM(1990)−TM(1994)) has also given equally useful information.

Ratio images have been generated by dividing the TM-4 (1990) image by the TM-4 (1994) image, and also conversely the 1994 image by the 1990 image. The areas of no-change get a value near unity, while areas that have undergone changes acquire values less than or greater than one, as the case may be. These images are also found to be Gaussian in nature. On carefully studying these images and by comparing them with the difference image, it was observed that the ratio images give a slight overestimation in results.

NDVI images have been generated using the TM-3 and TM-4 data for 1990 and 1994. A difference image was then generated by subtracting the above NDVI image of 1990 from the NDVI image of 1994, called NDVI-difference image (Townshend and Justice 1995). On this image, the areas where vegetation has decreased and opencast mining has increased appear in dark tones, while areas where vegetation has increased appear in bright tones. These results were confirmed by field check. No-change areas appear in grey tones.

The above output images were smoothened by a convolution matrix to suppress noise and then colour coded to highlight the changes in land-use patterns (figure 7).

3.3. Colour display

Colour display has involved thresholding, density-slicing colour-coding and IHS transformation. For the JCF, the field data have served to control the selection of threshold boundary between areas of change and no-change. Then the change detection images have been density-sliced and colour coded to demarcate the areas that have undergone maximum change from the areas that have undergone relatively lesser amount of change. Further, IHS transformation, on the lines followed by Prakash et al. (1995), has been applied to generate the final change detection image. On the IHS processed image (figure 8), hue is from the density-sliced colour coded difference image, intensity is from TM-4 image and saturation is constant. Areas of change appear in shades of green, yellow and pink, while the no-change areas appear in greyish-blue. Topographic relief, structural features, major roads, railway lines, main drainage, coal bands and dumps, etc. appear in the background on this image.

4. Discussion and interpretation

4.1. Changes in land-use pattern

Several changes in land-use pattern have occurred in the JCF and these are visible on processed Landsat TM images. The most striking change is that both opencast and underground mining has increased. Formerly vegetated or sparsely populated or barren areas now show opencast mining. Increase in mining activity is apparent in the entire coal belt area, though it is particularly prominent in some localised pockets. On the processed IHS change detection images, areas where coal mining has intensified or expanded, are depicted in green and yellow (figure 8). In the western part of the coalfield, north of Phularitand, the expansion in mining is most noticeable (figure 9).

Though vegetation in the JCF has shown an overall decrease, at some places new plantations have come up which is manifested in the processed difference NDVI images (figure 7). Some areas that were earlier excavated and showed dark tones, have now been levelled out. These areas appear bright on the black-and-white difference images and are also coded in red in figure 7. Recently, settlements and the
Figure 7. Density-sliced colour-coded NDVI difference image of an area near Angarpathra.

Figure 8. IHS processed change detection image of the western part of the JCF. Areas that have undergone changes (green, yellow and pink) are seen against the greyish-blue background (from TM 4). Topographic relief, structural features, drainage and transport network appear in the background.
Factors causing changes in land-use pattern

Several factors are involved in causing changes in the land-use pattern in JCF. In this study only the impact of opencast mining, subsidence, fires and anthropogenic activity is investigated.

Opencast mining, which is being given greater importance for present and future operations, has thoroughly changed the natural topography of the area (Ghosh 1989, Rathore and Wright 1993). Large pits are left after mining and large amounts of overburden material excavated during mining is dumped in the vicinity of the mine sites. Continuous rehandling of the overburden dumps further modifies the general landscape of the area. Flow of silt from overburden dumps causes degradation of transport network have expanded. This is distinctly evident on the remotely-sensed images (figure 10).
land and disruption of water flow. Increase in areas affected by open-cast mining is clearly manifested in the multidate images of the JCF (figure 9).

Subsidence has led to a prominent mark on the general topography of the JCF as over 35 km\(^2\) area is presently under subsidence (Malhotra 1987). There are numerous causes of subsidence (Saxena et al. 1991, Singh and Saxena 1992), the main ones are partial stowing of the mine areas, extraction of seams below the already worked seams and those close to ground surface and occurrence of subsurface fires.

Fires in the coalmines increase the temperature of the ground surface, making it unfit for sustaining many plant and animal species. Noxious fumes arising out of the fires are hazardous to the inhabitants of the fire affected areas. Fire is also mutually related with subsidence, one being the cause of the other. In the JCF, 18 km\(^2\) area is estimated to be under coal fire (Prasad et al. 1984).

Human factor is very significant in bringing about changes in the land-use pattern.
in the JCF. It is inferred from the remote sensing images that there has been an expansion in the transport network and in settlement in many parts of the JCF. Figure 10 shows the comparison between multisensor images for the years 1975, 1990 and 1994 for the area around Dhanbad. The effect of anthropogenic activities is obvious in the area.

6. Concluding remarks

Based on the results of this study, the following broad conclusions can be drawn:

1. Using remote sensing-GIS techniques supported by ground data, a variety of land-use classes were identified in the JCF. These are dense vegetation, sparse vegetation, fire, open cast mining, overburden dump, subsidence and barren wasteland, transport network, river, and water pond.

2. No single enhancement technique is sufficient for providing information on all land-use types. Useful enhancement techniques for land-use studies include edge enhancement of TM NIR and SWIR band images, false colour compositing (FCC of TM bands 4, 3 and 2; FCC of TM bands 5, 4 and 2; and FCC of TM bands 7, 5 and 3), colour manipulation, image ratioing (NDVI image), image differencing and IHS transformation.

3. Normalisation of image data is very necessary for the comparison of remotely-sensed data acquired at different dates.

4. Considerable changes in land-use in the JCF were recorded during the period 1975–1990. Open cast mining areas have increased tremendously, vegetated areas have undergone a general decrease though at some sites new plantations have come-up under reclamation schemes. Coal fire areas have expanded as new fires have nucleated. Settlements and transport network have expanded.

Therefore, remote sensing-GIS techniques are very useful for differentiating and identifying various land-use classes and for land-use change detection. This study was based on data from Landsat MSS, Landsat TM and IRS LISS-II. However, inputs from other sources, e.g., SPOT PANCHROMATIC data, IRS 1C data, SAR interferometric data, aerial scanner data etc., would make comparative study more interesting.

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References


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