MONITORING SUBSURFACE COAL FIRES USING SATELLITE-BASED OBSERVATIONS

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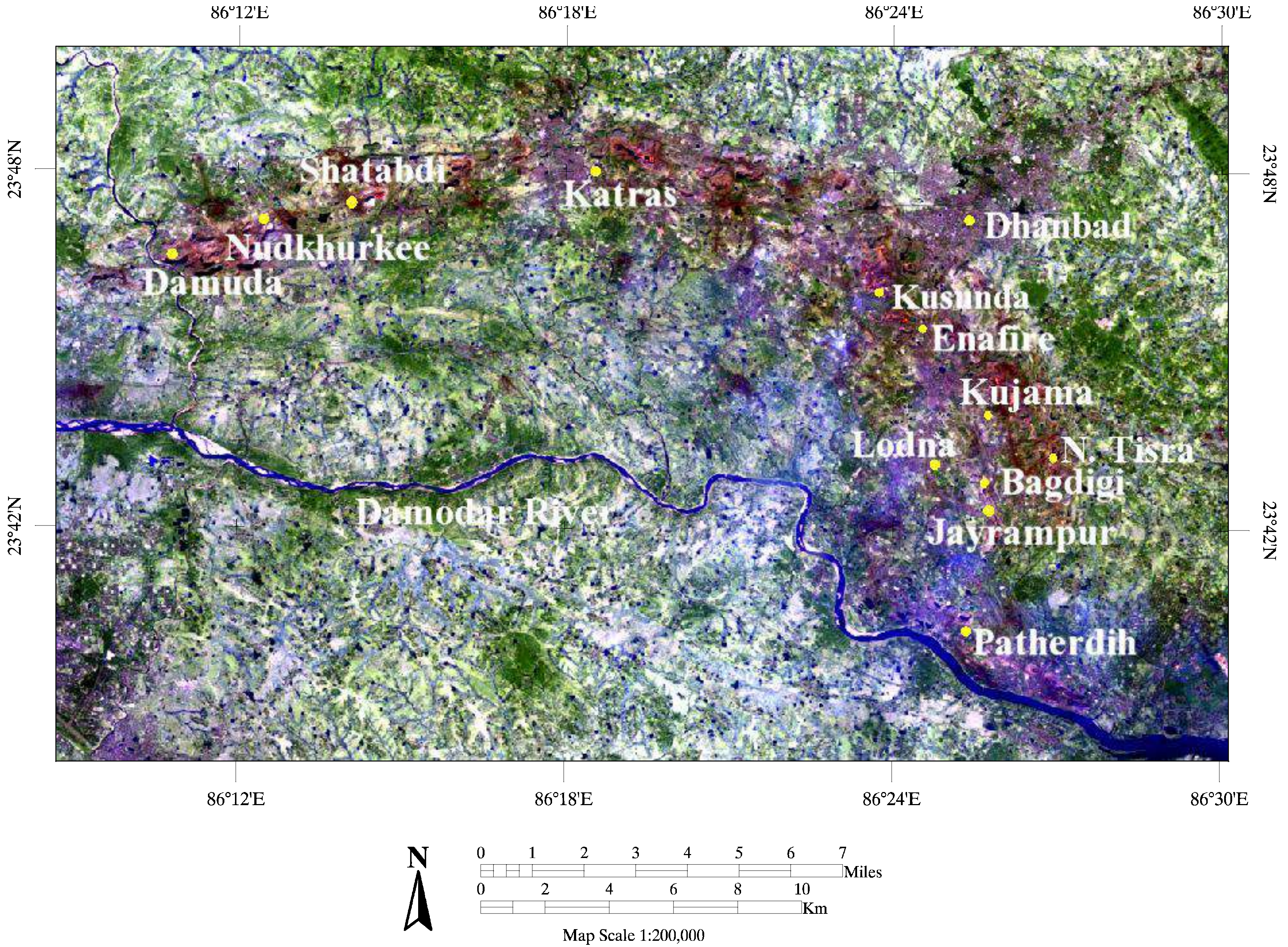
Jharia Coalfield

State of
Jharkhand:
Eastern India

Very High
Grade
Coking Coal

- Coal seams
- Sandstone
- Shale

Area:
450 Km^2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Shatabdi
Katras
Nudkhurkee
Damuda
Dhanbad
Kusunda
Enafire
Kujama
Lodna
N. Tisra
Bagdigi
Jayrampur
Damodar River
Patherdih
N
0 1 2 3 4 5 6 7 Miles
0 2 4 6 8 10 Km
Map Scale 1:200,000

Jharia Coal Fire:

- Jharia coalfield has been burning for nearly a century.

- The first fire was detected in 1916.

- As of 2007 more than 400,000 people who reside in Jharia are living on land in danger of subsidence due to the fires.

- Several natural and man-made factors have aggravated the problem.

Need for monitoring Jharia Coal Fire:

- Jharia Coalfield hosts the maximum number of uncontrollable surface and subsurface coal fires in India.
- Jharia coal fires cause loss of valuable, non-renewable, reserve of prime coking coal.
- Coal fire adversely affects the regional environment.
- Land subsidence associated with coal fire is considered a major havoc.
- Severe socio-economic, environmental and health impacts.

Previous Studies

- Utilization of LANDSAT-5 TM thermal band for coal fire detection.

- Utilization of LANDSAT-5 TM TIR and SWIR bands for surface and sub-surface coal fire detection.

- Utilization of LANDSAT-5 TM and LANDSAT-7 ETM+ TIR for studying coal fire dynamics.

STEP 1:
Pixel-wise spectral radiance computed for Landsat 5 TM and Landsat 7 ETM+

STEP 2:
Spectral radiance converted to radiant temperature

STEP 3:
Conversion of radiant temperature to kinetic temperature

$$\mathbf{T_{kin} = T_{rad} / \varepsilon^{1/4}}$$

Where,

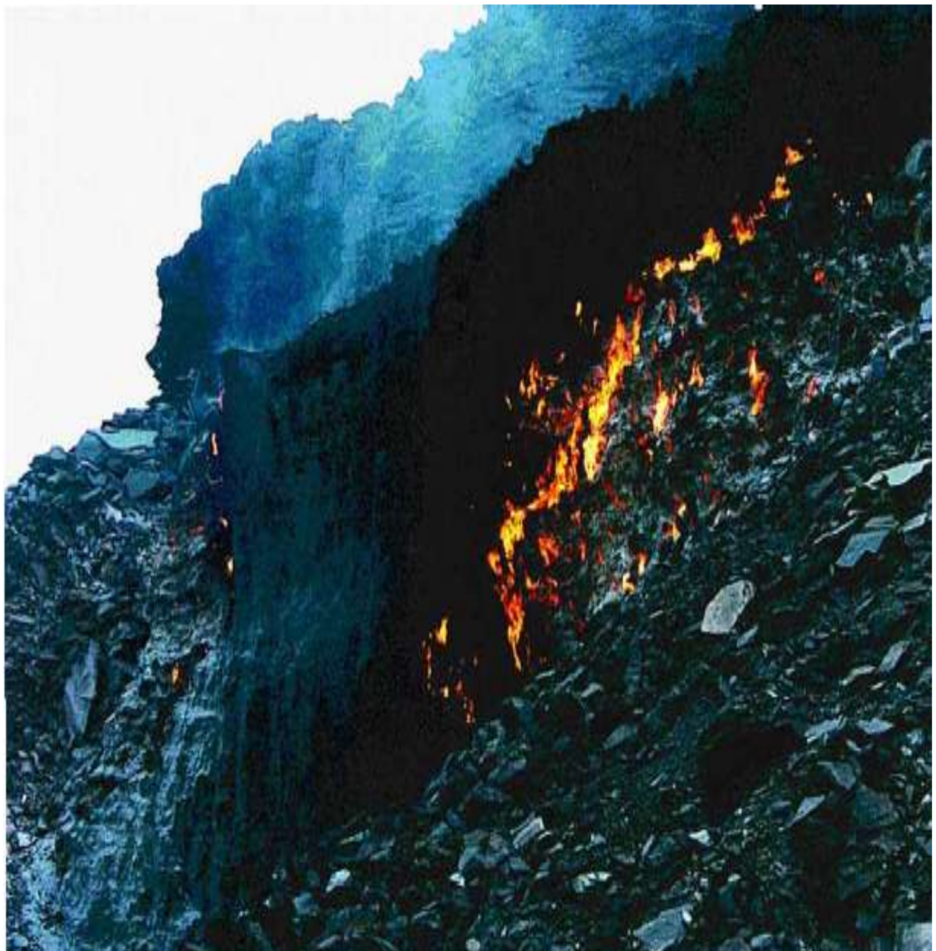
ε = 1 for areas covered by coal and water

= 0.92 for areas covered by rocks, presumably sandstone and shale

= a + b*ln(NDVI) for areas with vegetation (a = 1.0094 & b = 0.047)

STEP 4:
Determination of threshold temperature values for surface/subsurface fires using field-based observations.

Comparative study of surface and subsurface fires

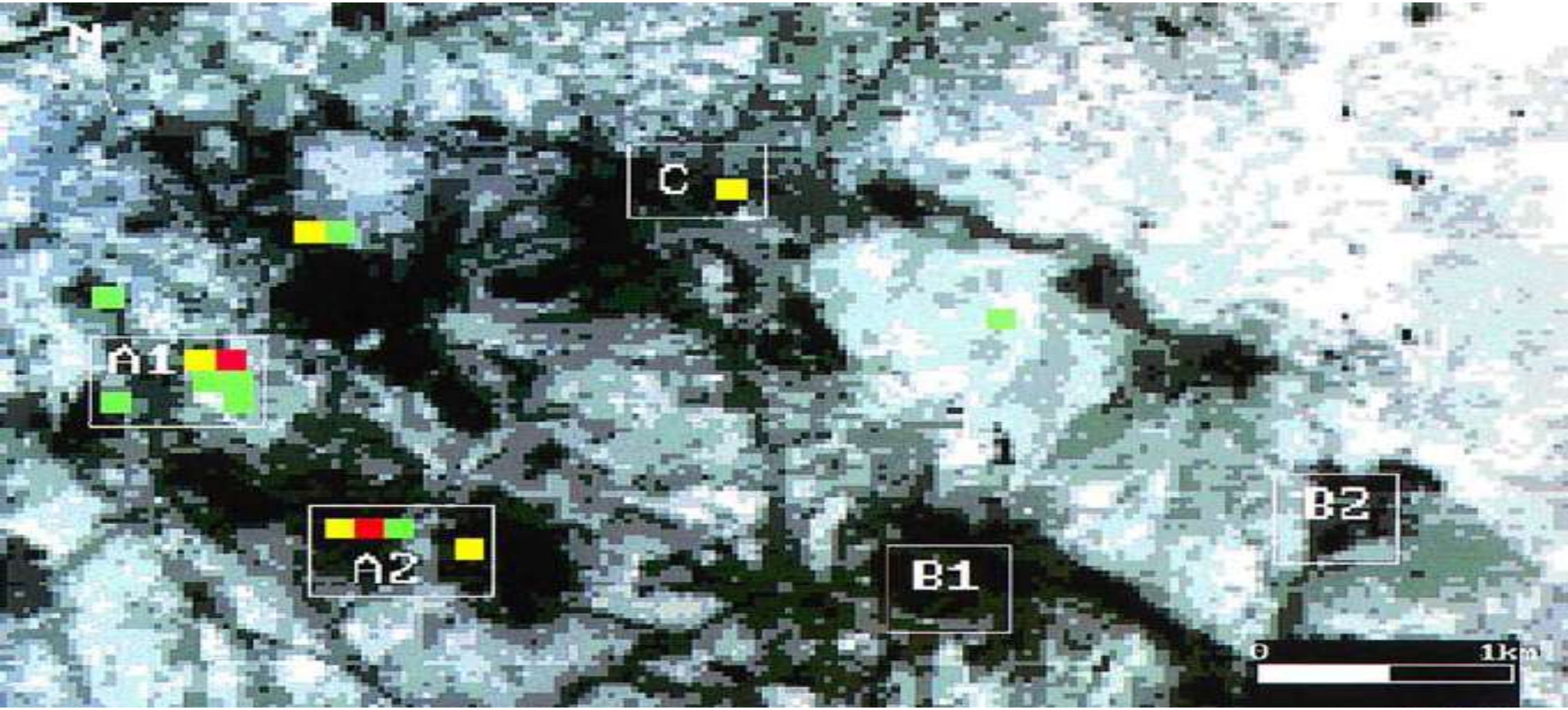


Field photograph of a surface fire in the JCF.

Field photograph of a subsurface fire-area in the JCF.

Subsurface Fires detection methodology:

- Landsat TM Band-6 of 1990.
- DN-values for the concerned image ranged from 117 to 152, corresponding to temperatures between 15.7 °C to 31.6 °C.
- DN value of 137/138 were adjudged threshold values for discriminating non-fire areas from the fire-areas.
- DN range of 138 to 152 corresponds to thermal anomalies associated with subsurface coal fires.
- Temperature of the anomalous areas range from 25.6 °C to 31.6 °C
- These temperature ranges are confirmed from field observations made in profiles over areas found to be anomalous in image data.



- TM image: 28 November 1990.
- Greyish-blue regions correspond to background temperatures from TM-6.
- Green, yellow and red depict successively higher temperatures associated with subsurface coal-fires from TM-6.

Prakash et al. 1997

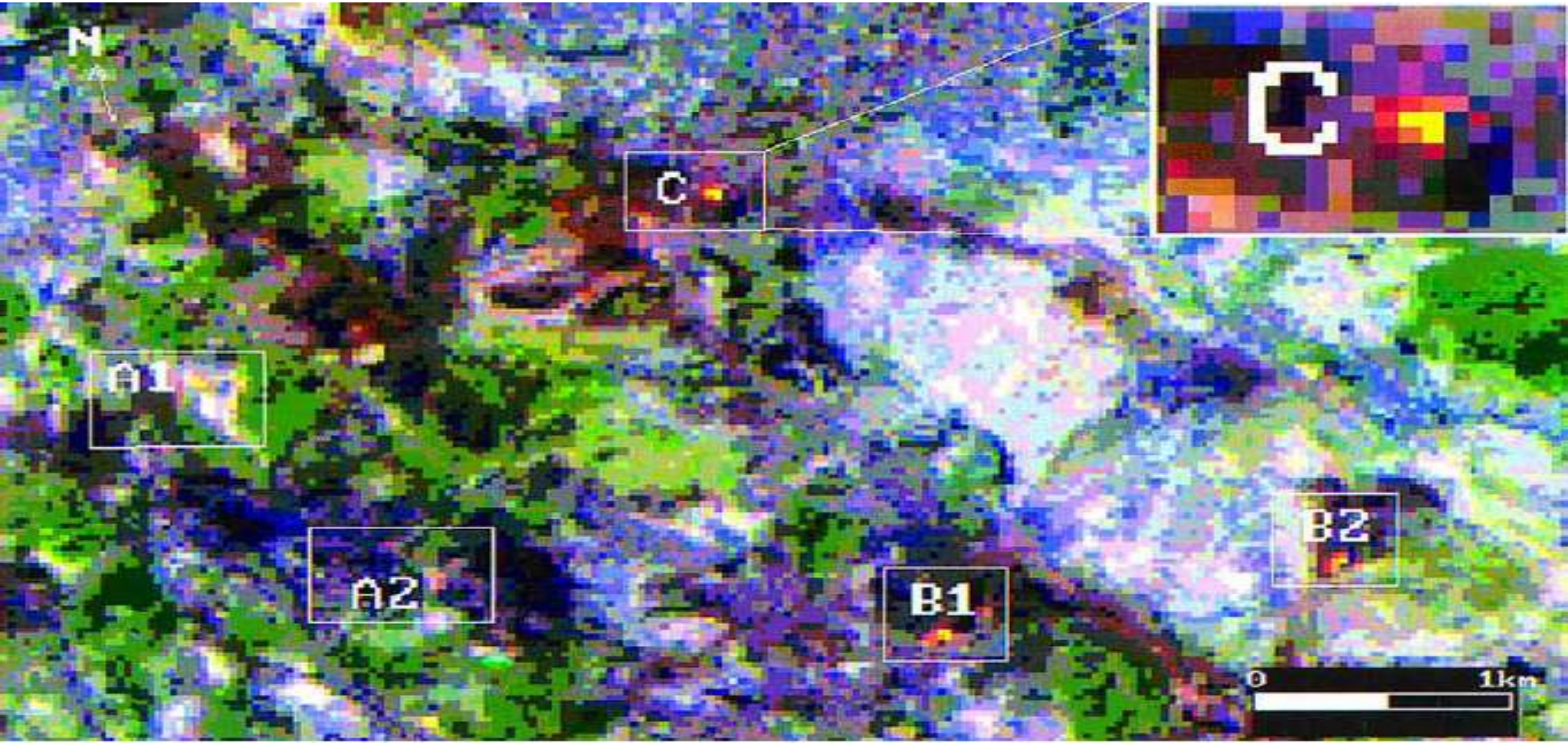
Surface Fire determination methodology:

- Shortwave infrared (SWIR) Landsat TM-5 and TM-7 data were used due to their capability to measure high temperature integrated over pixels.

- Surface fires, causing high radiant values in SWIR, were identified on the basis of distribution of DN-values in TM-5 and TM-7.

- Pixel integrated temperatures were calculated using TM-5 & TM-7 data ranged from 217 °C to 276 °C).

- A detailed pixel-wise study indicated surface fires in 59 pixel locations.

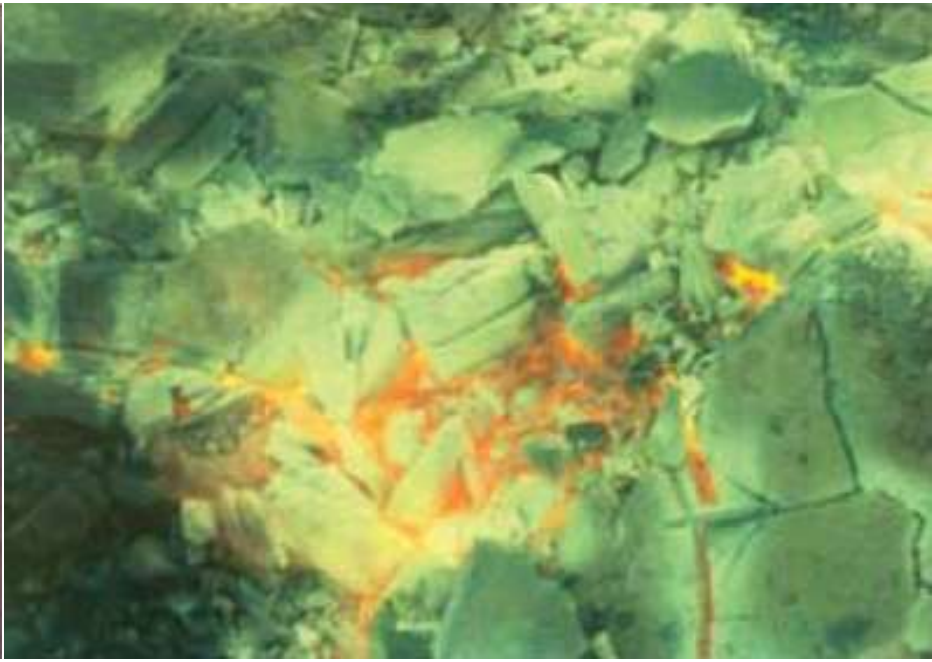


- FCC generated by coding TM-7, TM-5 and TM-3 in RGB, respectively.
- Yellow points depict highest temperatures and red pixels relatively lower temperatures associated with surface fires (see inset).

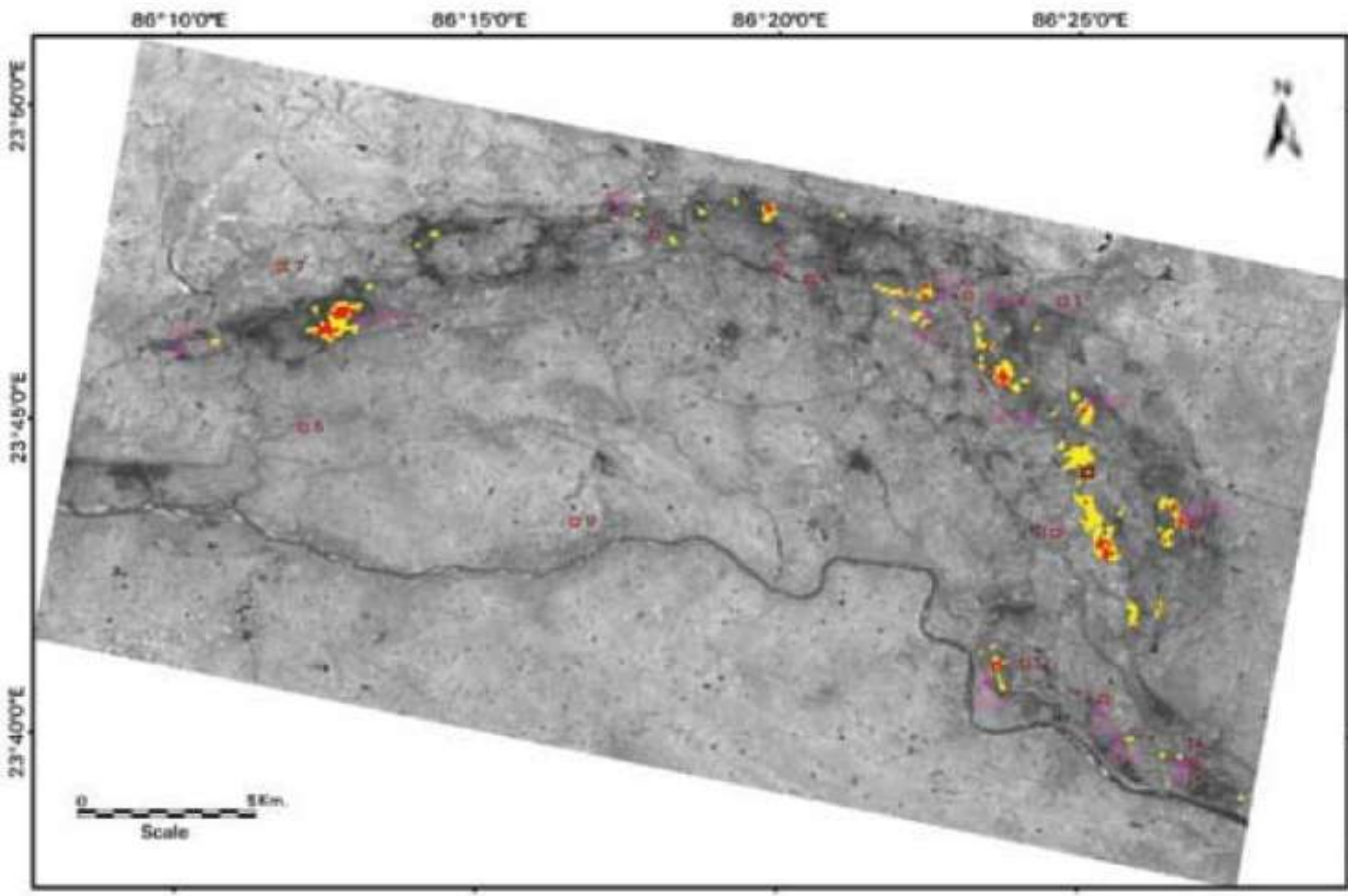
Prakash et al. 1997

Dynamics of coal fire in Jharia Coalfield

Subsided seam fire

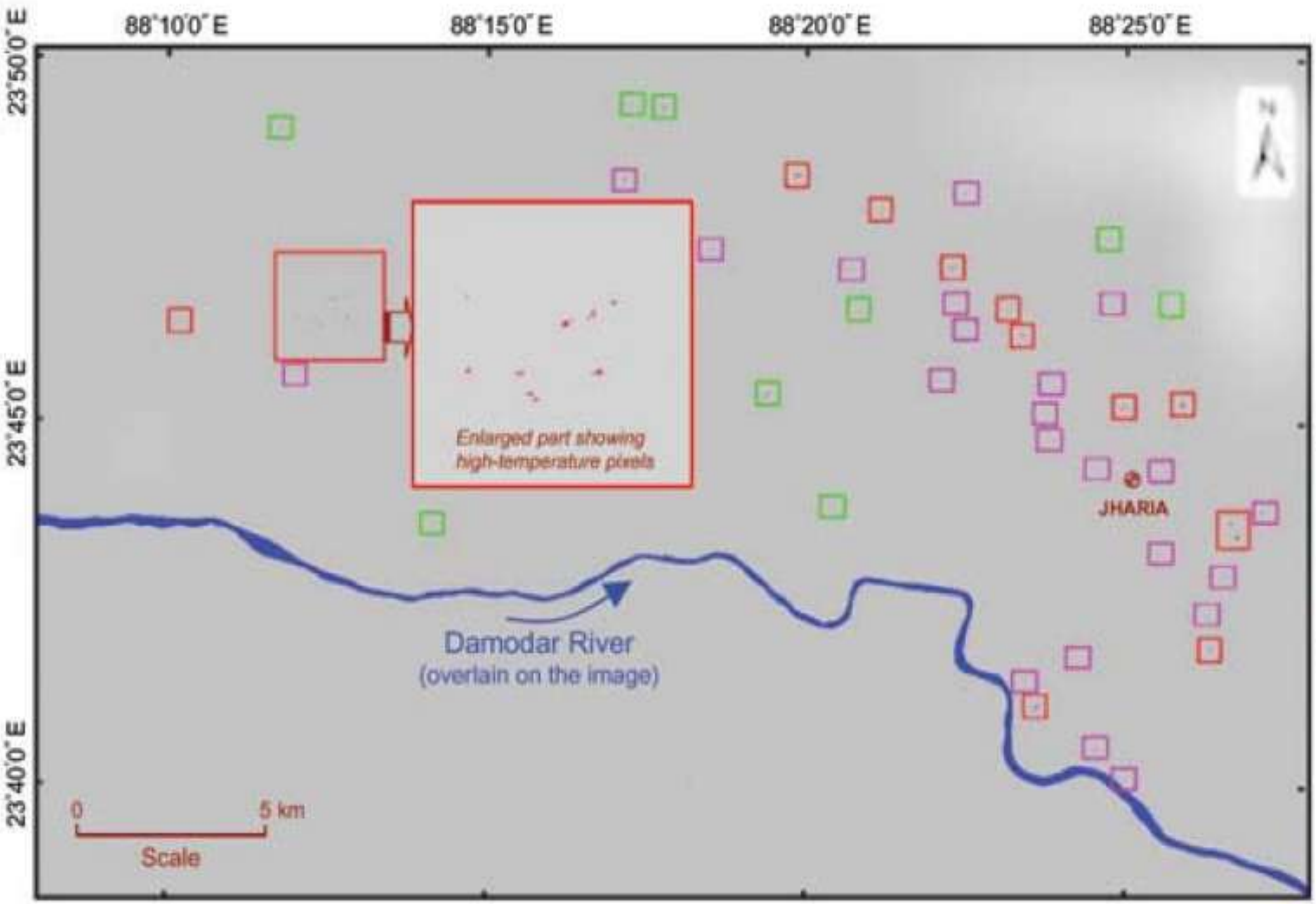


Debris fire



Surface (Red) and subsurface (Yellow) coal-fire areas of Jharia Coalfield during 1992 obtained from night-time Landsat-5 TM band 6

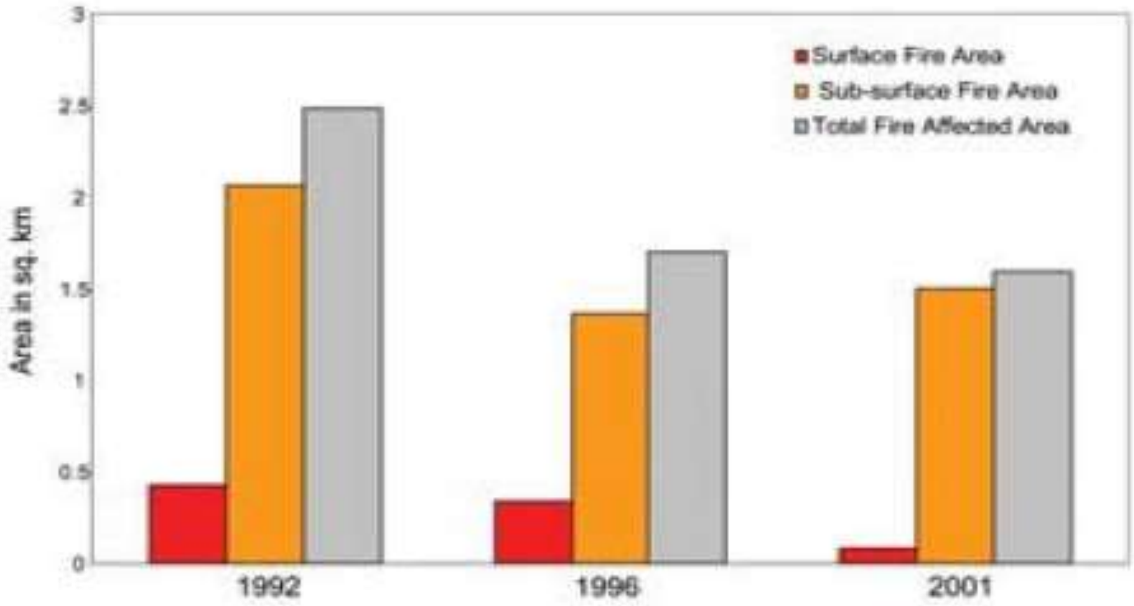
Chatterjee et al. 2007



Surface coal-fire pixels (outlined by red and purple rectangles) are precisely identified from night-time Landsat-5 TM band 7 data of Jharia Coalfield acquired in 1992

Chatterjee et al. 2007

The total coal fire-affected area in Jharia Coalfield (including surface and subsurface fires) was found to decrease from 2.49 sq. km in 1992, to 1.70 sq. km in 1996 and to 1.59 sq. km in 2001, which accounts for a decrease of ~32% during 1992–96 and ~6.5% during 1996–2001.



Bar diagram showing changes in spatial extent of surface (Red), subsurface (Orange) and total fire-affected areas (Grey) in Jharia Coalfield in 1992, 1996 and 2001.

Need for InSAR study:

❖Previous studies, relying on the use of thermal band, helped in observing coal fire but could not provide means of early warning.

❖They provided no means to generate risk warnings to people residing in the vicinity of subsidence prone area.

Objective:

To study subsidence as a proxy of subsurface fire due to the direct correlation between these two from field observations: Coal looses consistency upon burning causing the top layers to subside.

Advantages:

A. Deep subsurface fires does not have surface signature to be detected by thermal band.
B. We can generate hazard map of regions using subsidence as a proxy of subsurface fire.

DATA USED

Envisat Advanced Synthetic Aperture (ASAR)

LANDSAT ETM+ images

SRTM DEM

Field survey map published by Bharat Coking Coal Ltd. (BCCL)

Methodology

1. Processing of Microwave data

1. Interferogram is generated from two coregistered SAR images with similar imaging geometries, acquired at different times, for the same area.

2. Interferogram is produced using Repeat Orbit Interferometry Package (ROI PAC) developed at JPL/Caltech.

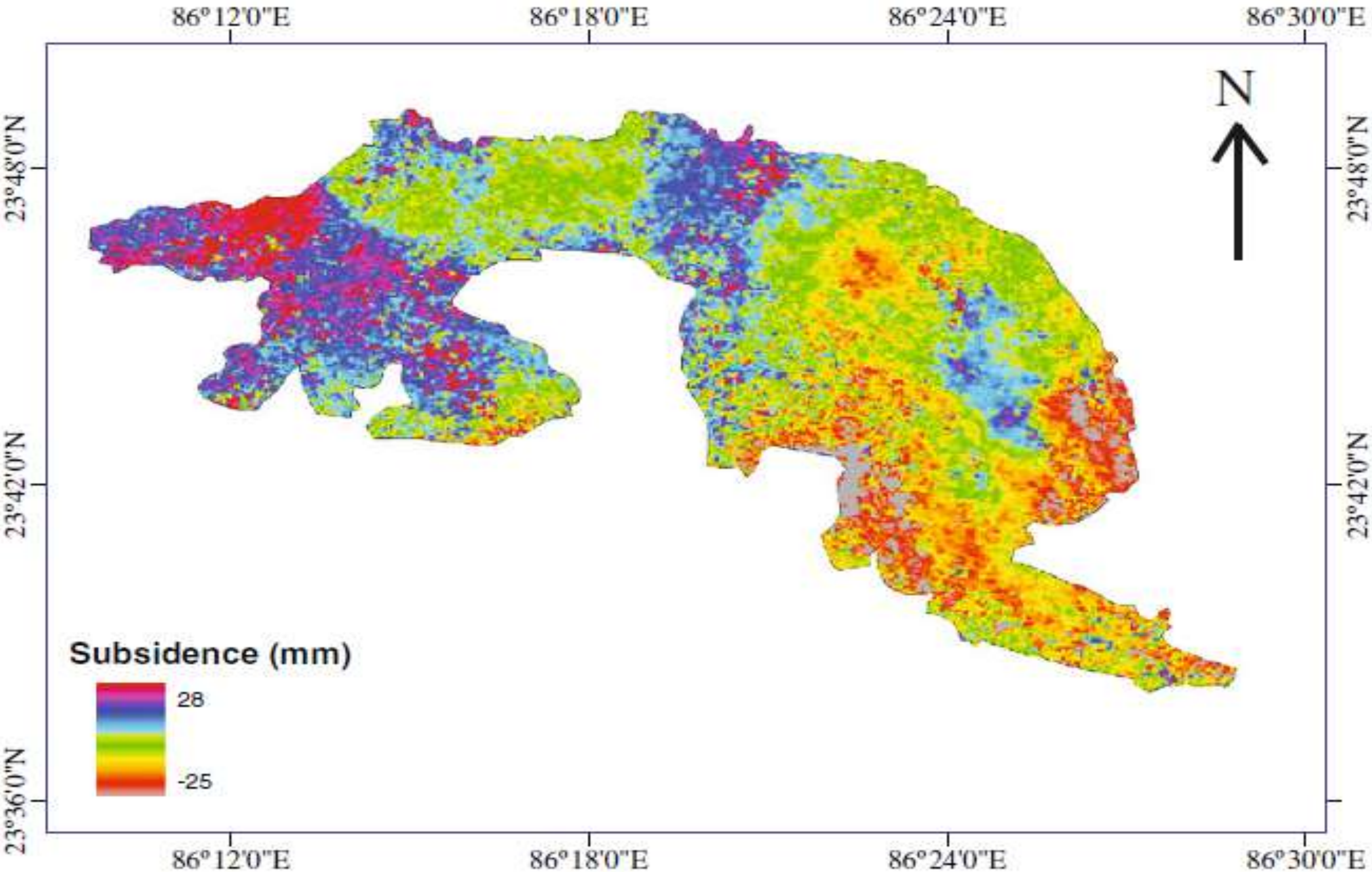
- The interferogram generated from two SAR images consists of a phase difference (Φ) produced by

$$\Phi = \Phi_{topo} + \Phi_{disp} + \Phi_{atm} + \Phi_{noise} + \Phi_{orbital}$$

Φ_{topo} = phase difference related to topographic information of the terrain
Φ_{disp} = phase difference related to the line-of-sight surface displacement between two acquisitions
Φ_{atm} = phase difference related to water content in atmosphere
Φ_{noise} = phase difference related to noise in the interferometric signal
$\Phi_{orbital}$ = phase difference related to relative positions of the satellite

- The Φ_{disp} is estimated by removing the phase differences contributed by other sources from the total.
- Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping (SNAPHU) is used to generate a displacement map from interferograms.

Subsidence map obtained DInSAR



- Both the eastern flank and western flank of the Jharia coalfield have witnessed major subsidence.

- Kujama, Kusunda, Tetulmari, North Tisra, Bararee and Lodna in the eastern flank and Phularitand, Damuda and Mahuda in the western flank are some of the major areas showing high magnitudes of subsidence.

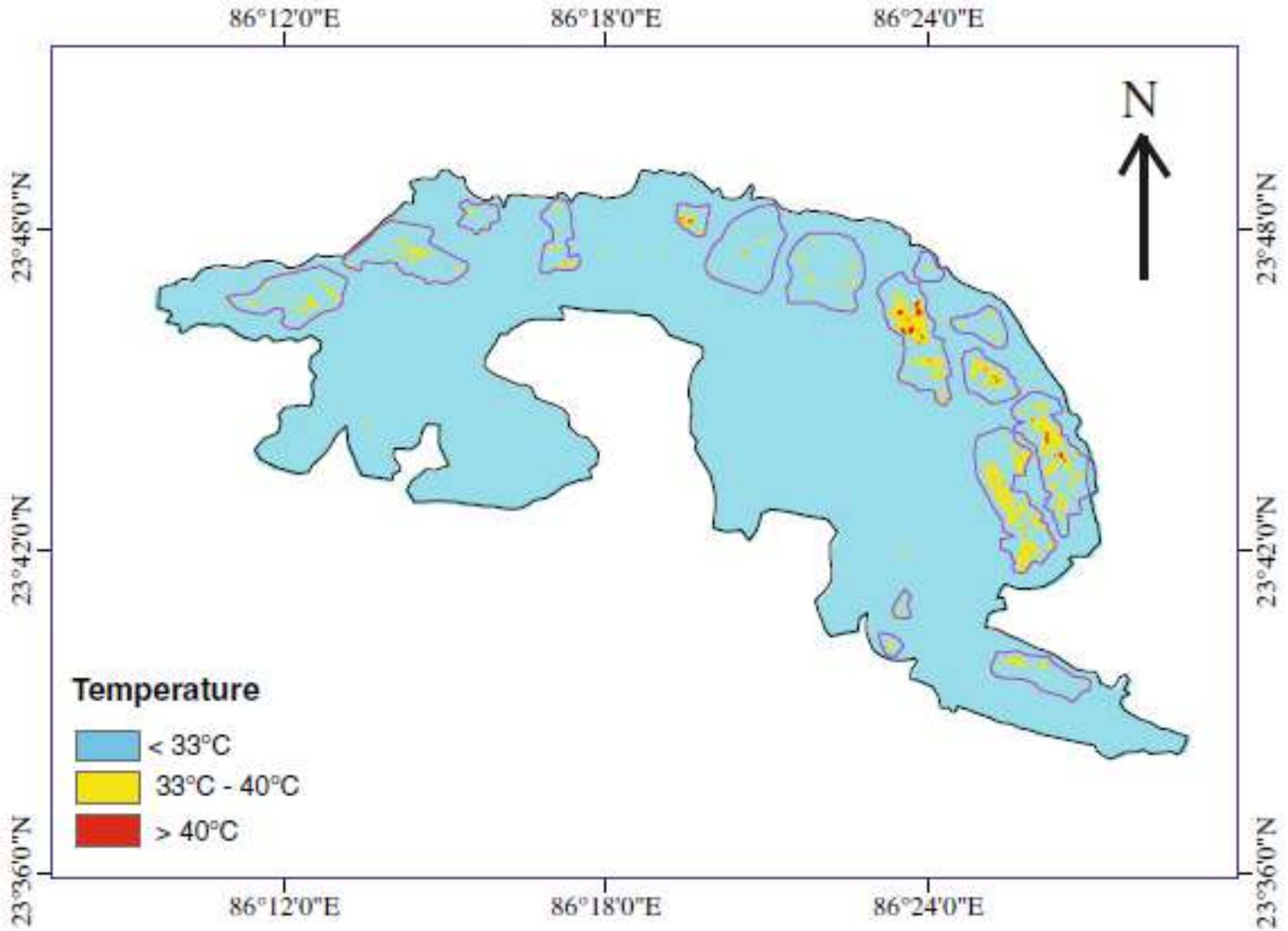
- Average displacement values range between −*25 mm (upliftment) and 28 mm (subsidence)*.

Limited mining activities, both in terms of spatial extent and magnitude

Use of small temporal baseline between the SAR image pairs limit the impact of mining-related subsidence in the displacement map produced

Primary cause is the occurrence of subsurface coal fires.

Validation of field surveys with Thermal IR data

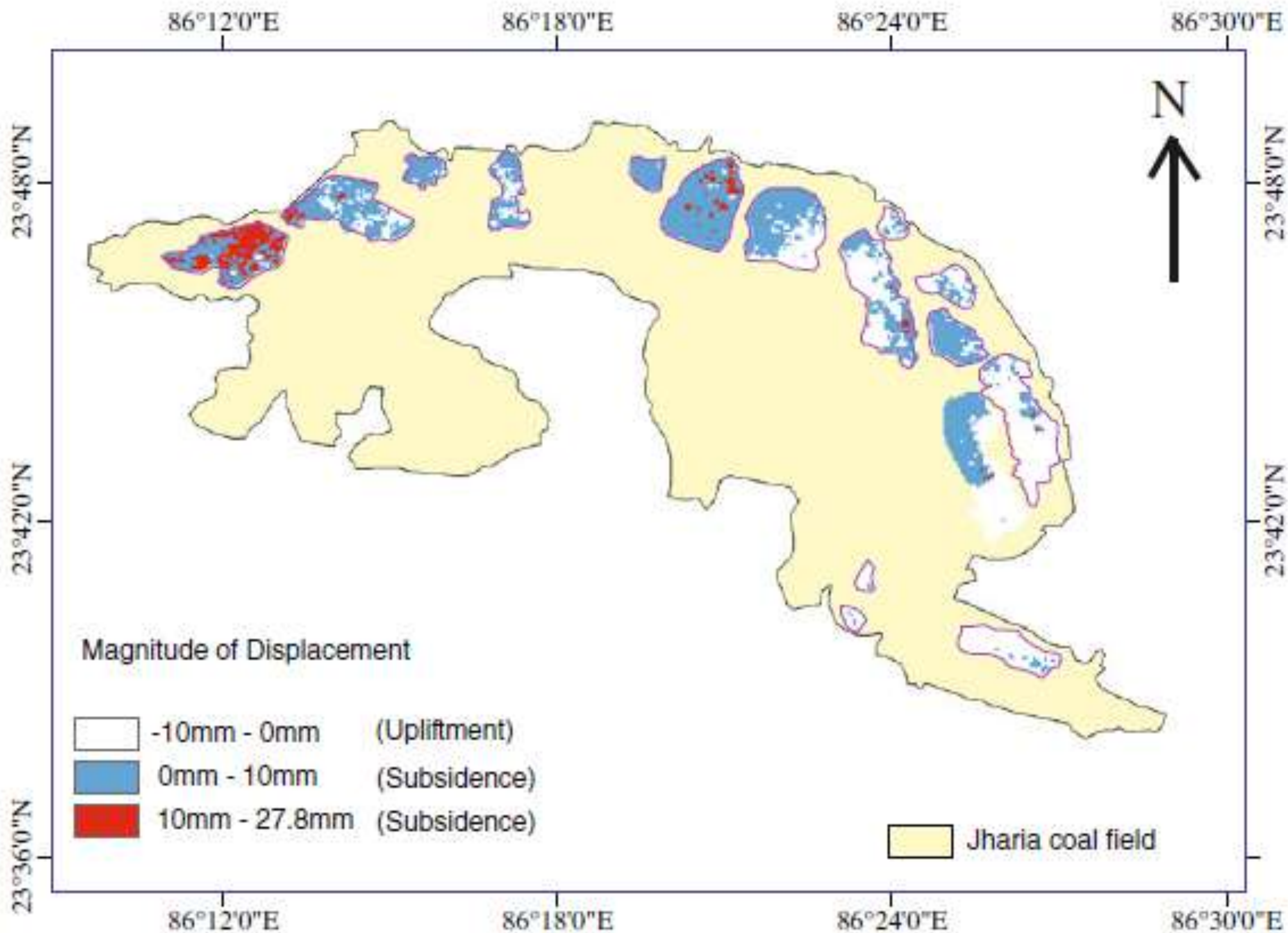


❖Coal fire map, generated from LANDSAT 7 ETM+ thermal band overlaid by georeferenced polygonal boundaries (purple colour) representing the spatial extent of surface and subsurface coal fire obtained from the field survey map.

❖Eastern flank of Jharia coalfield is more affected by surface and subsurface coal fires than the western flank.

❖Collieries like Rajapur, Tisra, Lodna, Ena industry, Kusunda and Kujama in the eastern flank and Shatabdi OCP, Block II and Damuda show strong thermal anomaly signals due to coal fires.

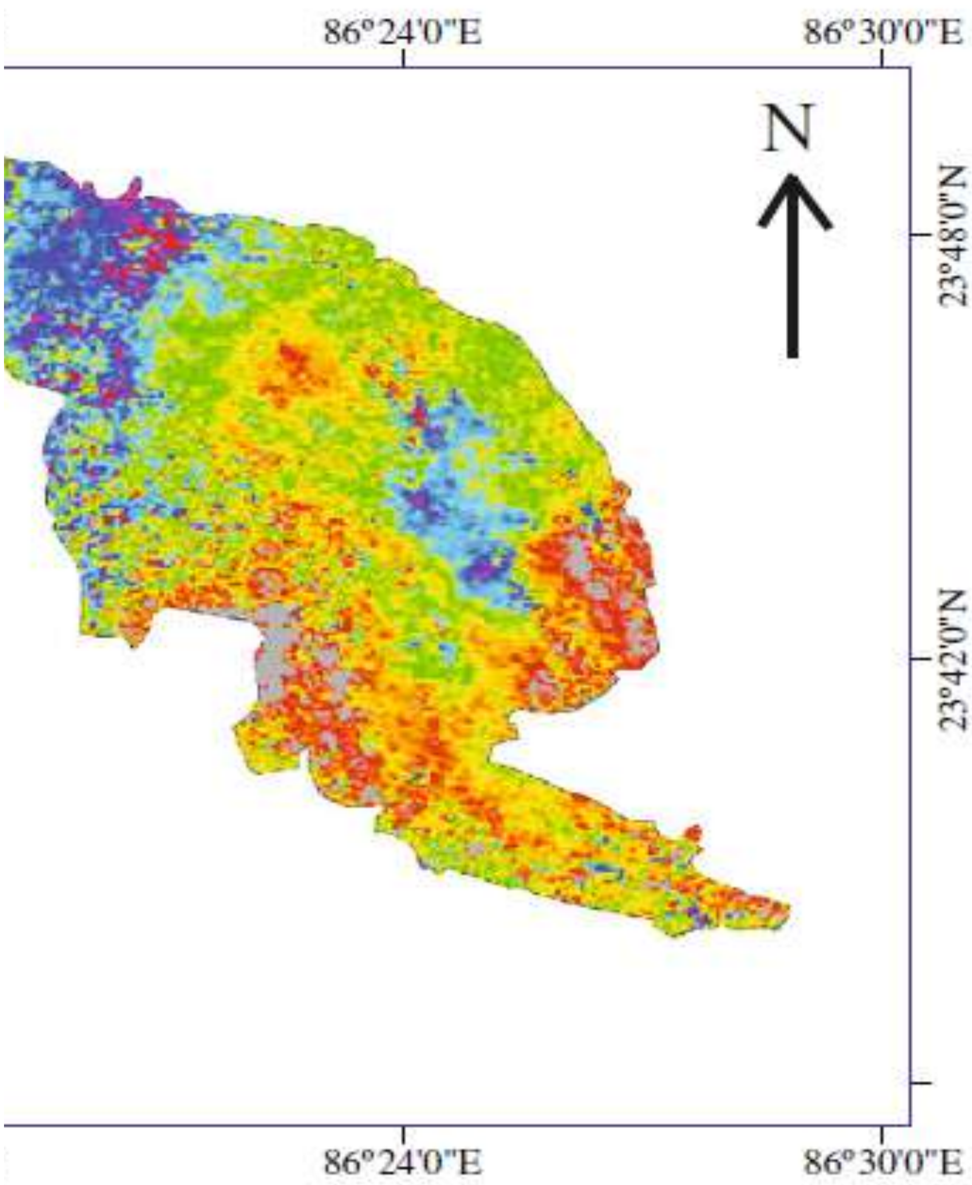
Validation of subsidence with field surveys



- Displacement map overlaid with georeferenced polygonal boundaries (red colour) representing areas with surface and subsurface coal fires prepared by BCCL.

- Reveals direct correlation between the spatial distribution of surface subsidence and the co-occurrence of subsurface coal fires.

- Majority of high magnitude subsidence observed in parts of Block II, Shatabdi OCP, Katras, Mudidih, Jogta, Bassuriya, Rajapur and Lodna collieries renowned for repeated instances of coal fire related hazards.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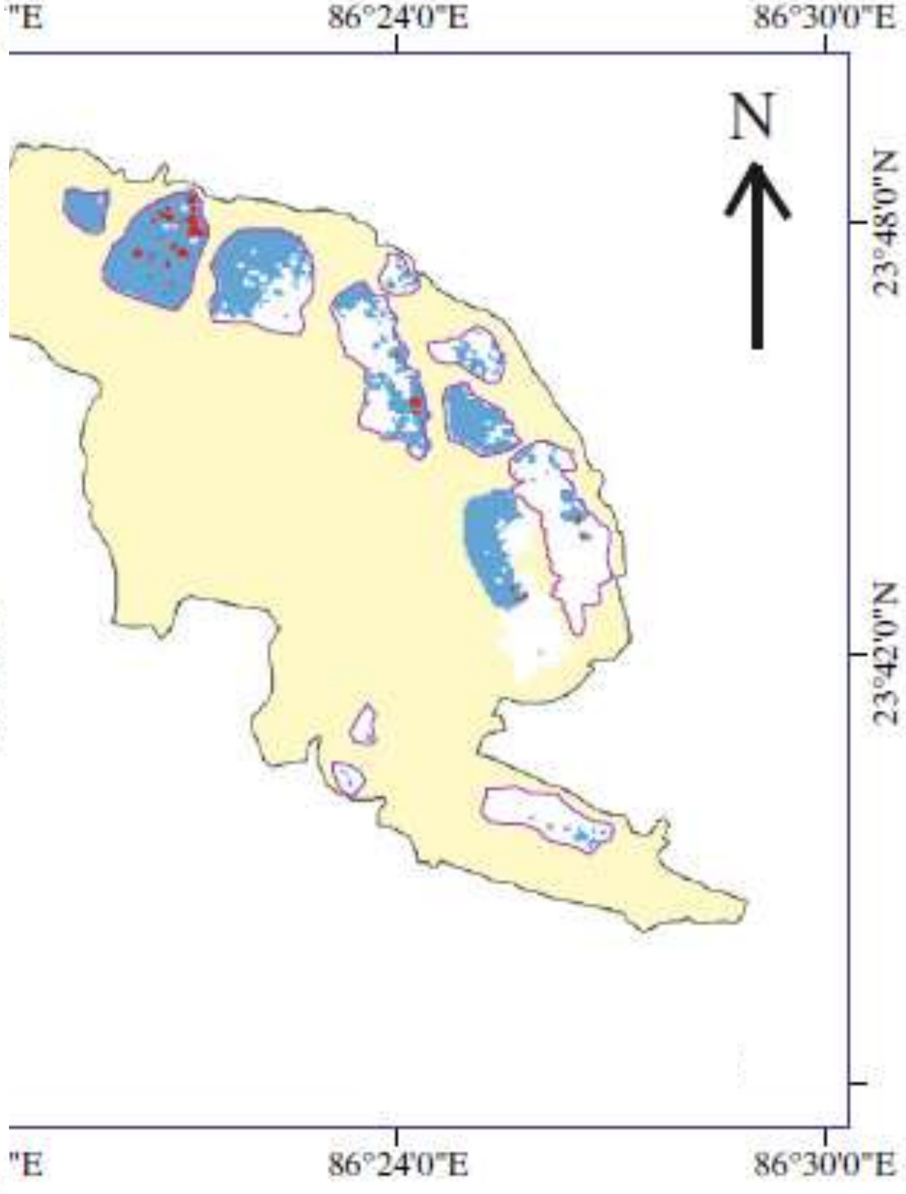
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Requirements for future work

- ❖Improvements in the algorithm for more precise measurements of subsidence.

- ❖More rigorous SAR acquisitions with small temporal baseline.

- ❖Field validation of the remotely sensed subsidence estimates using GPS/level surveys.

- ❖Similar observations from multiple satellites

THANK YOU

2. Processing of LANDSAT ETM+ images:

STEP 1:

Conversion of DN values to radiation values using the Markhem and baker equation:

$$L_\lambda = \frac{Lmax(\lambda) - Lmin(\lambda)}{Q_{cal\ max}} \cdot Q_{cal}$$

Where,

$L_{min(\lambda)}$ = minimum detected spectral radiance of the scene

$L_{max(\lambda)}$ = maximum detected spectral radiance of the scene

Q_{cal} = grey level of the analyzed pixel

$Q_{cal\ max}$ = maximum grey level (255)

STEP 2:

Conversion of radiant values to radiant temperature using the following equation:

$$T = \frac{K_2}{\ln (K_1/L_\lambda - 1)}$$

Where,

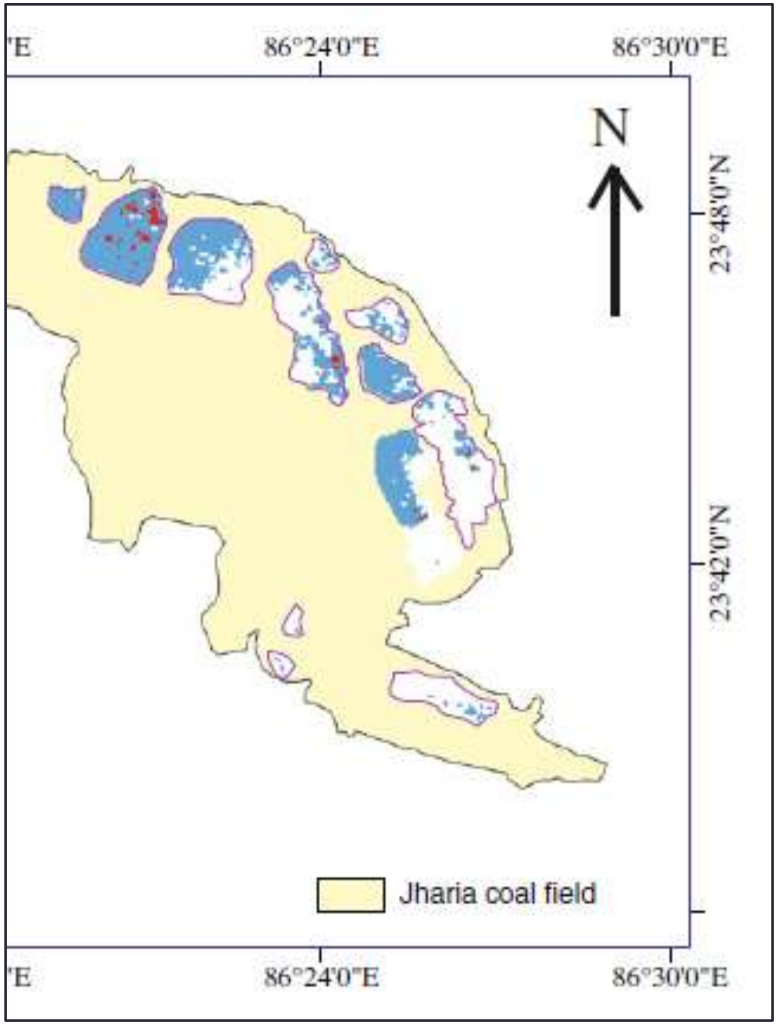
K_1 = calibration constant (666.09 W/m2/sr/μm)

K_2 =calibration constant (1281.71 K)

STEP 3:

Conversion of radiant temperature to kinetic temperature using the following equation:

$$T_{kin} = T_{rad} * (1/ \varepsilon^{1/4})$$



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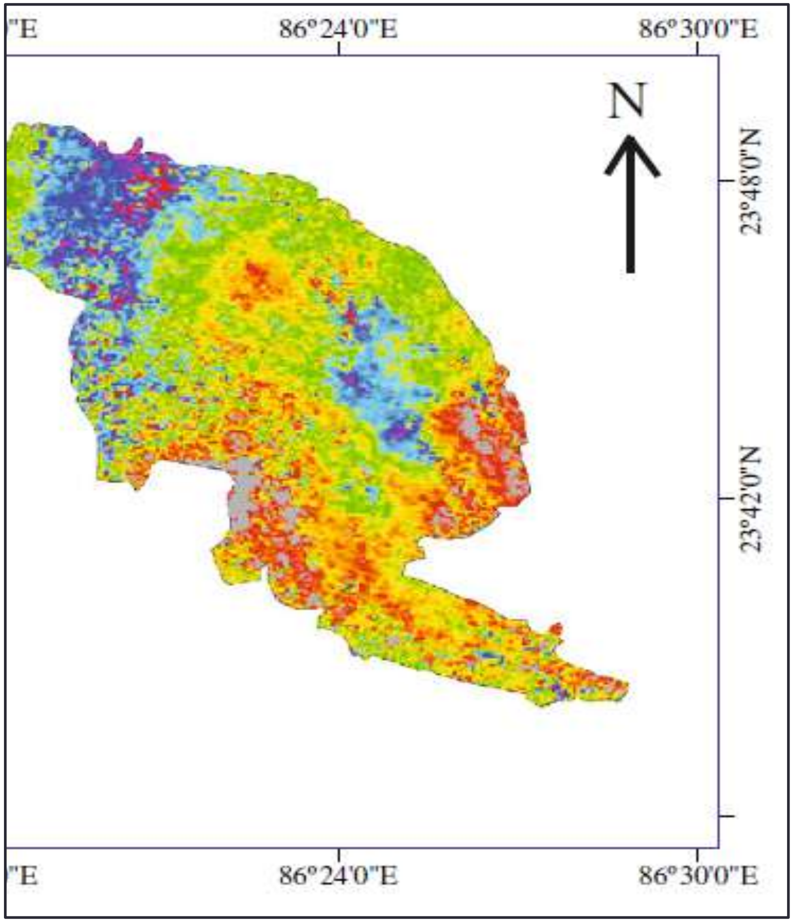
Jharia coal field



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