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Application of remote sensing to assess environmental impact of limestone mining in the Ariyalur district of Tamilnadu, India

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Abstract: The Ariyalur district of Tamilnadu is enriched in limestone deposits of Cretaceous sedimentary system. The limestone is being commercially exploited for decades as it serves as a raw material in cement manufacturing industries. The mining activity resulting in upraising of dust clouds has had severe impact on the surrounding environment affecting its vegetation and land surface temperature (LST). By using Landsat 8/OLI and Landsat 7/ETM data, vegetation pattern in terms of normalised difference vegetation index (NDVI) and LST was determined for three buffer zones within 10km radius of the mines for two time windows of 2001 and 2015. The results clearly indicate that vegetation decreased by 29.99%, 16.62% and 29.58% in zone I, zone II and zone III respectively between two time windows, whereas LST shows an increase by 6.9%, 9.48% and 8.94% in zone I, zone II and zone III respectively from the year 2001 to 2015**.** The study reveals significant changes in NDVI and LST across three buffer zones which may be related to upraising of chemically active limestone dust clouds into open atmosphere and consequent dispersal over the adjoining soil and vegetation cover. The dust load has affected the plant photosynthesis and growth thus leading to notable changes in vegetation, induced by limestone mining activity in the Ariyalur district.

Keywords: Environmental impact, Limestone mining, Cretaceous sedimentary system, Ariyalur district

1. Introduction

Mining of economic minerals from the earths' crust has been one of the world's earliest and important human activities after agriculture (Mondal et al., 2014). Unsystematic mining activities of surface and subsurface tend to make a significant impact on the environment, resulting in reduction of forest cover, erosion of soil, pollution of air, water and land and reduction in biodiversity (Woldai, 2001; Ranade, 2007; Iqbal et al., 2013). More than 80000 ha of land are presently under various types of mining operations in India causing rapid changes to Land use/Land cover (LULC) patterns. Therefore, regular assessment and monitoring of Land use changes imposed by mining activity is necessary at constant time intervals.

Geospatial data have been extensively used now for LULC mapping and environmental impact assessment and monitoring of mining activities (Rathore and Wright, 1993; Jhanwar, 1996; Charou et al., 2010). Environmental hazards related to pollution, change detection of vegetation and mining impacts can be more effectively assessed and monitored by remote sensing techniques (Stefouli and Tsombos, 1998; Woldai, 2001; Latifovic et al., 2005; Vorovencii, 2011). Therefore, remotely sensed data is widely used now in surveys and applications beyond land-use land-cover change studies due to the increased perception by researchers, professionals, Governments and Industry (Baynard, 2013).

The state of Tamilnadu has vast limestone deposits with a total reserve of 1473 million tonnes (Equbal and Ambica, 2012). The Ariyalur district comprises most of the reserve, where mining for this valuable mineral has been pursued since early 1950s. The limestone is organic in nature occurring in Cretaceous sedimentary system of the Cauvery Basin. Three lithological formations namely Dalmiapuram of Albian, Gaudamangalam of Coniacian-Santonian and Kallankuruchchi of Early Maastrichtian age contain vast deposits of limestone. Over 37 mines are being excavated in about 1512 hectares of land as on 2015. The mining area has increased by about 36.94% from 2001 to 2015 and therefore this area offers a good case study for assessment of environmental impact using remote sensing.

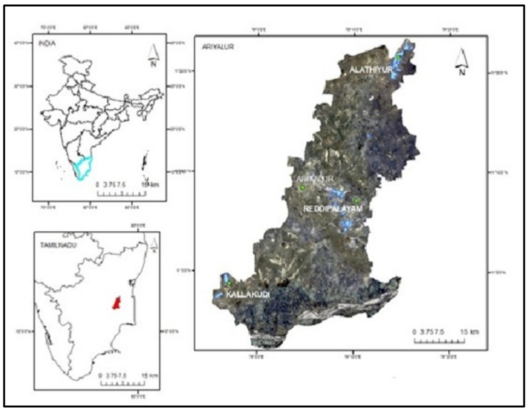

Figure 1: Location map of the Ariyalur district

The present study is mainly aimed at evaluating the impact of limestone mining on the surrounding environment within 10km radius of mines using remote sensing techniques. In view of sparse publications on mining related environmental impacts, this study will form the baseline work for future comparison and assessment of environmental impacts in the study area. The objectives of the study are:

- To map Limestone quarries in the Ariyalur district.
- To analyse time sequential changes of vegetation due to mining
- To examine the impact of mining on Land surface Temperature

2. Study area

2.1. Characteristics of study area: Geographic location of the study area, Ariyalur district is shown in Fig.1. The Ariyalur district is located in central part of Tamil Nadu state and is 265 km away from the state capital Chennai. It is situated between 10.54^o to 11.30^o of the Northern latitude and 78.40^o to 79.30^o of the Eastern longitude. The district has an area of 1949 km^2. It is an inland district without sea coast. The district is closely bordered by Vellar river in the north and Kollidam river in the south and it has no well marked natural divisions. The soil types are dominantly ferruginous with loamy texture varying in color from red at the surface and yellow at the lower horizon having good drainage. The soils are free from salt and carbonates with low amount of organic matter, nitrogen and phosphorus with adequate amounts of potash and lime. Red loam soil is prevalent in Sendurai, T. Palur, Andimadam, Jeyankondam blocks and black soil in Thirumanur and Ariyalur blocks of the district. The major crop grown in the district is Cashew nut which occupies 77.56% of cultivable land.

2.2. Geological setting

The limestone deposits occur in Cretaceous sedimentary system of the Cauvery basin. The cement grade limestone is exploited mainly from Dalmiapuram, Garudamangalam and Kallankurichchi formations of Cretaceous period. The limestone in the Dalmiapuram formation predominantly produced by algal-coral-bryozoan organisms and contains more than 95% $CaCO_3$. The Garudamangalam limestone is a gastropod shell rich coquinite, whereas Kallankurichchi limestone is enriched in Gryphaea shells. The overburden consists of Cuddalore sandstones followed by Quaternary alluvium. The stratigraphic succession of the study area is given in table 1.

Table 1: The stratigraphic succession of the study area

Period	Stage	Formation	Lithological Description
Late Cretaceous	Late Maastrichtian	Kallamedu Ottakovil	Fluvial sandstone with cross laminations. Silty sandstones of estuarine origin with trace fossils.
	Early Maastrichtian	Kallankurichchi	Ferruginous and arenaceous limestone with gryphaea abundant in the middle part.
	Campanian	Sillakudi	Predominantly sandstone of shelf origin with tracefossls.
	Coniacian-Santonian	Garudamangalam	Gastropod rich limestone occasionally dolomitic.
	Cenomanian-Middle Turonian	Dalmiapuram	Marl in the upper part.
			Marl with calcareous sandstone alternations in the middle.
Early Cretaceous	Albian		Coral algal limestone at the bottom.
	Aptian	Terani	Kaolinitic clays with plant fossils and sandstone alternations of fluvial origin.
Archaean	Basement		Granite gneiss

3. Data used and methodology

3.1 Data used

Landsat-8 OLI/TIRS (2015), Landsat-7/ETM (2001)

3.2 Methodology

The remote sensing data Landsat-8 OLI/TIRS (2015), Landsat-7ETM (2001) are accessed from USGS website. The Arc GIS 10.2 and Erdas Imagine 9.1 are the main software used to analyse and integrate the data in GIS platform. Various stages of methodology are given in the flow chart in Fig. 2.

3.2.1. Mapping of limestone mines: The mine locations in the Ariyalur district were obtained from the Department of Geology and Mining at Ariyalur town and were positioned on Google Earth. Then the digitization of mine locations for the years 2001 and 2015 was done using *Add Polygon* tool from Google Earth. After completing the process, polygon feature was saved as *kml file*. Using Arc GIS 10.2, the digitized mines locations were saved as *kml format* and converted into layer using *kml to layer* option from conversion tool. Then the layer digitized was displayed and mine maps were prepared for two time series of 2001 and 2015 (Fig. 3).

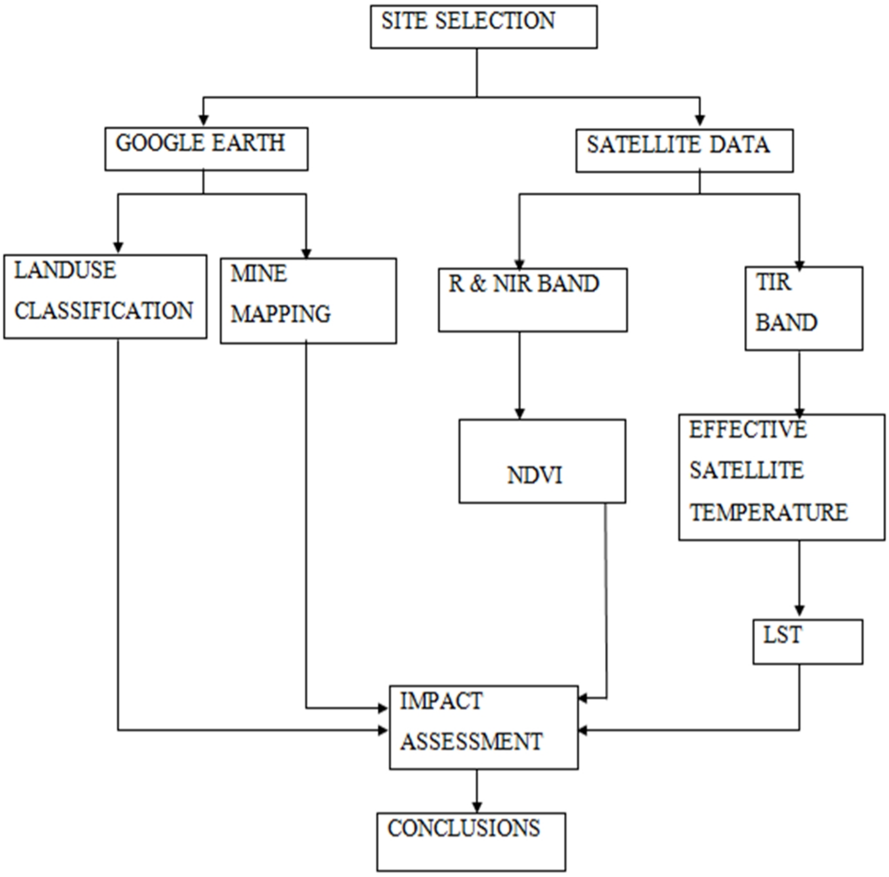

Figure 2: Details of steps followed in the analysis of data

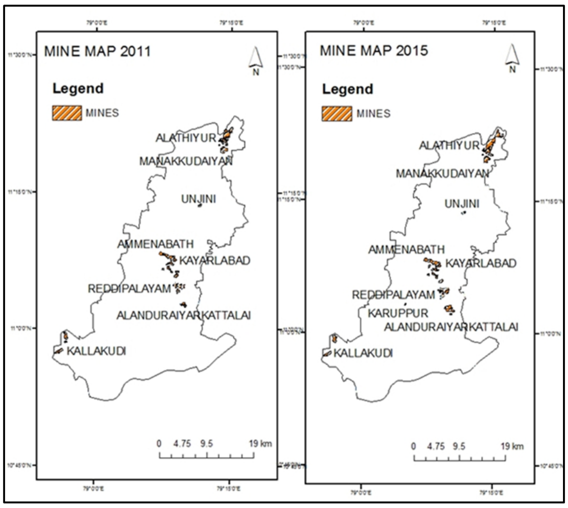

Figure 3: Limestone mines map of the Aniyalur district for the year 2014 (Left) and 2015 (Right)

3.2.2. Calculation of NDVI and LST

NDVI: The Normalized Differential Vegetation Index (NDVI) was calculated from the visible and near-infrared bands of Landsat-8 OLI/TIRS and Landsat-7/ETM data.

NDVI= (NIR-RED) / (NIR+RED)

NDVI for a given pixel always ranges from minus one (-1) to plus one (+1) as Bare soils give a value close to zero and very dense green vegetation have values close to +1.

LST: The Landsat-8 OLI/TIRS and Landsat-7/ETM datapertaining to bands 4, 5, 10 and11 (thermal infrared- in case of Landsat 8) were used for generating LST images. The raw data were corrected for radiometric errors and their digital number (DN) were converted to radiance, then to reflectance and brightness temperature and finally Land Surface Temperature (LST) were derived from the above expressions using *Raster Calculator* tool in Arc GIS 10.2.

The conversion steps are as follows:

1) conversion to TOA radiance:

$$\mathbf{L_\lambda = M_L Q_{cal} + A_L}$$

where,

L_λ = TOA spectral radiance (Watts/ (m^2 * srad * µm))

M_L = Band-specific multiplicative rescaling factor from the metadata.

A_L = Band-specific additive rescaling factor from the metadata.

Q_{cal} = Quantized and calibrated standard product pixel values (DN).

2) conversion to at-satellite brightness temperature

Conversion from spectral radiance to brightness temperature using the thermal constants as provided in the metadata file:

$$T = K_2 / \ln((k_1/L_\lambda) + 1)$$

where,
T = At-satellite brightness temperature (K)
L_λ = TOA spectral radiance (Watts/(m^2*srad* µm))
K_1 = Band-specific thermal conversion constant from the metadata as shown in table 2.
K_2 = Band-specific thermal conversion constant from the metadata as shown in table 2.

Table 2: Thermal conversion constant for Landsat 8 and Landsat 7 (source:USGS)

Thermal constant	Band 10 (Landsat 8)	Band 11 (Landsat 8)	Band 6 (Landsat 7)
K1	1321.08	1201.14	1282.71
K2	777.89	480.89	666.09

$$LST = T / [1 + (\lambda \times T/P) \ln(e)]$$

where,
T = At-satellite brightness temperature
Λ = Wavelength of emitted radiance
p = h * c/ s
h = Planck's constant (6.626*10E-34 Js)
s = Boltzmann constant (1.38*10E-23 J/K)
p = 14380

$$e = 0.004Pv + 0.986$$

where,

P v =Proportion of vegetation

$$Pv = [(NDVI - NDVI\ min) / (NDVI\ max - NDVImin)]^2$$

4. Results and discussion

For evaluation of environmental impact by limestone mining in the Ariyalur district, two commonly used parameters i.e. NDVI and LST were employed. The change detection for two time windows of 2001 and 2015 was out. The % changes for over 15 year's duration were correlated with changes in mines area for three buffer zones.

NDVI is used to to assess the condition/vigour of vegetation and its change with time. The NDVI maps for the years 2001 and 2015 were generated for assessing the vegetation condition in the study area. A reclassification technique was performed using *Reclassify tool* in Arc GIS 10.2 to delineate vegetation alone from NDVI maps. Three Buffer zones of 10 km radius as per guidelines of Ministry of Environments and Forests (MoEF), Govt. of India (Ranade, 2007) were delineated around the mines using *Buffer* tool in Arc GIS 10.2 and the changes in vegetation were mapped (Fig. 4). The reclassified NDVI map generated from Landsat 7- ETM of 2001 reveals that the area of vegetated surfaces were 113.76 km^2, 139.68 km^2, 267.51 km^2 in Zone I, Zone II and Zone III respectively. Similarly, the reclassified NDVI Map, derived from Landsat 8/OLI of 2015, reveals that the vegetated surface area were 79.64 km^2, 116.45 km^2, 188.42 km^2 for Zone I, Zone II and Zone III respectively. The difference in vegetation index as computed shows -29.99%, -16.62% and -29.58% decreases in vegetated surface in Zone I, Zone II and Zone III respectively from the year 2001 to 2015.

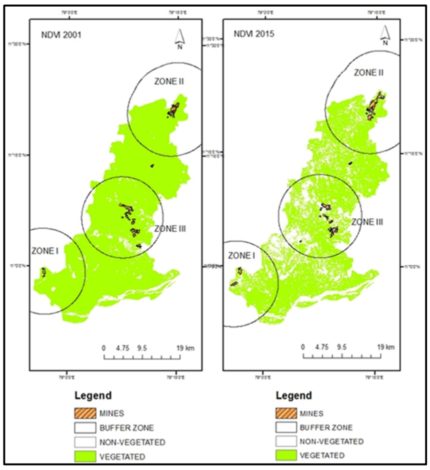

Figure 4: Vegetation changes in the buffer zones in the Aniyalur district for year 2001 (Left) and 2015 (Right)

Turner (2012) observed that lot of dust particles upraised due to mining activity get suspended in the air and potentially affect the surrounding vegetation. Chemically active dust, such as highly alkaline limestone dust can affect the pH of the soil (Asubiojo et al., 1991; Katare et al., 2015) and the plant surfaces and thus become toxic to the plant (Farmer, 1993). The cumulative impact of dust loading is a reduction in the plants photosynthetic abilities and therefore growth (Larcher, 1995; Gleason et al., 2007). The analogous effects are envisaged in the mining area of the Ariyalur district, where rapid changes in vegetation cover may be related to upraising of chemically active limestone dust clouds into open atmosphere, then dispersing and concealing the large tracts of soil and vegetation cover, hindering plant photosynthesis and growth, due to intensive limestone mining activity between 2001 and 2015.

LST is an important parameter in formulating surface-atmospheric relations Sobrino et al., 2003). Surface temperature is one of the major factors constraining vegetation productivity, therefore the trend and variability in NDVI need be explained considering the influence of surface temperature (Latifovic et al., 2005).

LST of earth surface depends upon exposed rocktypes, soil texture, soil moisture, vegetation cover, surface water bodies and land use pattern (Kamila and Chandra Pal, 2015). However, the most important among these are the richness of water and vegetation (Alshaikh, 2015). Therefore, Land use/Land cover is an important factor which exerts significant impact on Earth ecosystem. In this study, *Raster Calculator* tool in Arc GIS 10.2 was used to derive LST (Fig. 5). The LST map generated from Landsat7-ETM of 2001 reveals that the mean surface temperatures were 28.97^{0}C, 28.80^{0}C, 30.31^{0}C in Zone I, Zone II and Zone III respectively. Similarly, the LST map generated from Landsat 8 of 2015, reveals that the mean temperature were30.97^{0}C, 31.53^{0}C, 33.02^{0}C. The surface temperatures indicate increase of the order of 6.9%, 9.48%, and 8.94% in Zone I, Zone II and Zone III respectively from the year 2001 to 2015.

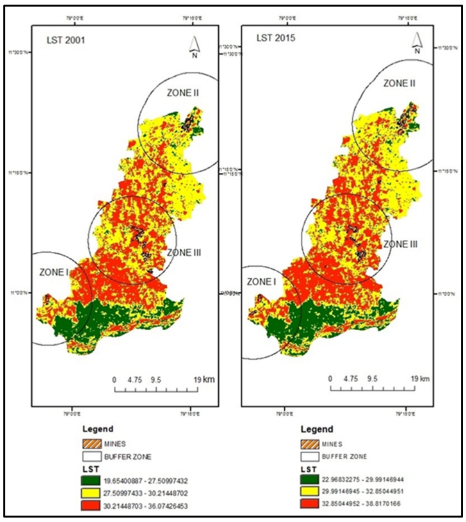

Figure 5: Spatial vegetation of land surface temperature in the Aniyalur district for year 2001 (Left) and 2015 (Right)

Considerable variation in LST of the study area can be attributed to land cover changes in terms of increased mining in vegetation cover due to intense mining activity (Kamila and Chandra Pal, 2015; Odunuga and Badru, 2015). The comparison of NDVI and LST for two time frames confirmed a good agreement in the patterns of NDVI and LST (Alshaikh, 2015). This further indicates that NDVI can be a reliable indicator of vegetation productivity and its sensitivity (Latifovic et al., 2005) to prevailing conditions in the study area. Also a close correlation is evident between reduction in vegetation and proportional increase of mining area for two time windows.

5. Conclusions

The environmental impact assessment of limestone mining in the Ariyalur district was analysed using Landsat 8 and 7 data. Landsat -8 OLI/TIRS for 2015 and Landsat-7 ETM for 2001 were used for limestone mine mapping in the Ariyalur district during 2001 and 2015 is about 39.34%. Three Buffer zones of 10 km radius surrounding the mines was delineated from north to south in the study area for comparative assessment of environmental impact. The vegetation zone radius from the mines shows decrease in vegetation by -29.99%, -16.62% and -29.58% in zone I, zone II and zone III respectively from the year 2001 to 2015.The LST map shows an increase in temperature by 6.9%, 9.48% and 8.94% in zone I, zone II and zone III respectively from the year 2001 to 2015**.** The change detection in NDVI and LST across three buffer zones shows a close positive correlation with proportionality of mine area. This correlation further suffices that increased limestone mining activity has an unambiguous environmental impact in the Ariyalur district. Decrease in the vegetation cover in the study area may be related to upraising of chemically active limestone dust clouds into open atmosphere, then spreading and concealing the large tracts of soil and vegetation cover, hindering plant photosynthesis and growth, due to intensive limestone mining activity between 2001 and 2015.The present study is an important contribution to understand the impact of limestone mining on surrounding environments in the Ariyalur district.

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