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Remote Sensing and GIS Enabled Approach for Environmental Impact Assessment in Mining Industry

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ABSTRACT

The upwardly projected mineral demands of the country have been apportioned to the production from larger opencast mines. While conceding to fuelling the economy of the nation, in corresponding proportions there occur issues of environmental alterations. Over the past, the mining industry has evolved through an era of understanding the concerns of the environment, assessing the various impacts from mining activities, forecasting changes in environment and thereby incorporating plans and practices in all levels to mitigate these unacceptable changes.

This article focuses on the issues related to the use of land, its excavation, its movement, and finally its reclamation and restoration for any further use. This paper presents the significance of remote sensing (RS) and geographical information systems (GIS) in providing accurate assessment of environmental changes in the mining industry. This paper cites two case studies in the coal mining and metal mining regions of India and emphasizes the integration of RS and GIS into the mining industry for performing effective impact assessment and environmental management.

Keywords: Environmental impact assessment, Land use land cover, Remote Sensing & GIS,

1. INTRODUCTION

Mining involves removal of useful minerals and disposal of waste at working site either from opencast or underground methods. The mining activity is performed in three major phases, viz., mine development, full production, post-mining rehabilitation. The potential impacts of mining include loss of forests, loss of top soil, changes in surface water bodies, interruption of natural drains, ground deformation, subsidence, acid mine drainage, effluents discharge. Also, air carries dust and other gaseous loads, and there occurs a loss of ecological habitat. These impacts of mining industry have been an object of wide research.

The exploitation of mineral resources has brought serious land problems. A large number of land resources are excavated, exploited and at times left unattended after mining. Therefore, while continuing to speed up development of mines, the land should be reclaimed not only to raise the utilization rate of land resources and keep the dynamic balance of the total area, but also to restore the ecological balance and promote the sustainable development of ecology, economy and society.

In line with the principle of conservation, preservation and restoration, the mining activities are tightly monitored and guided by the statutes. These laws ensure safety, productivity, mineral conservation, socio-economic benefits, and protection of the environment. After the mining operations start, there is a need to concurrently deploy the environmentally sustainable measures. The landscape within mine area undergoes changes as mine advances. The mining landscape has to be restored to its pristine conditions. The mining industry conducts the environmentally sustainable activities like preservation of top soil, reclamation of pits, biological reclamation of the dumps, improving the ecological habitat, topographical and habitat restoration. However, all these activities need to be well planned and integrated with the mining operations. To achieve a post-mining landscape that exceeds pre-mining land-use patterns shall be the most apt objective of the mining reclamation operations.

2. ENVIRONMENTAL IMPACTS DUE TO MINING

The environment undergoes a large scale change continually in the form of land displacement, altered landscape function, formation of large pits, formation of craters due to subsidence, formation of acidic drainage, soil pollution, biomass loss, air pollution, etc. Many of these problems can be avoided, if adequate environmental control considerations are thought of during conceptual stage of the project.

Environmental pollution due to mining activities has been reported in many countries. Among anthropogenic activities, mining is a major source of trace metal contamination that can release constituent elements into the surrounding environment through wind and water-runoff erosion. Both active and abandoned mining sites have a serious environmental impact on terrestrial and aquatic ecosystems. Decong et al (2013) collected the soil samples from the vicinity of the Tongling mining area, China. Decong et al evaluated the bioavailability of trace metals (Cu, Zn, Pb and Cd) to vegetables by comparing different methods (trace metals in DTPA, EDTA, HCl, NH_4NO_3, NH_4OAC aqueous solutions and total metals in garden soils),and assess the potential health risks of trace metals to the local population via vegetable consumption. The results showed that the mean values of total Cu and Cd in the soil samples exceeded the national standard in China. Average concentrations of Cd and Pb in some vegetable samples were higher than the maximum permissible concentration.

Research was conducted on the evaluation of landscape function through the monitoring of physical landscape parameters (i.e. water regime, soil characteristics or the thermal conditions of the site). The synthesis of these parameters enables the various “stabilizing”, “risky” and “neutral” landscape segments to be located and visualized (Lubomír et al., 2012).

Walsh et al (2001) assessed the relationship between plant biomass levels and selected social, bio physical and geographical variables. This study depicted the importance of social and bio-physical factors on plant bio-mass at different spatial scales and temporal periods.

Since, the impacts tend to be myriad; it was proposed to ascertain the environmental impact through scientific environmental analysis of the affected parameters. Castilla-Gómez (2015) proposed a methodology to establish an environmental analysis focusing on the evolution of environmental impacts over time on landscape ,subsidence, water courses, acid mine drainage and waste. The impact weighting techniques was implemented to determine the global environmental impact.

Srivastava et al (2014) experimented with the use of fly ash as a soil ameliorant for its deployment in reclamation of mine overburden and lowland in Jharia coalfield. This study revealed that the characteristics of mine spoil and lowland significantly improved (except N and K), photosynthetic rate and soil conserving efficiency of the planted species enhanced, and concentration of SPM, RSPM, CO_2, SOx, and NOx reduced significantly over the control.

3. REMOTE SENSING APPLICATIONS FOR ENVIRONMENTAL IMPACT ASSESSMENT

Remote sensing provides an ability to observe and collect data for large areas relatively quickly, and is an important source of data for further analysis and inference. Remote sensing for environmental monitoring is an important tool for studying different aspects of ecosystems at local, regional and global scales. Remote sensing has the added advantage of acquiring data with sufficient area coverage and temporal frequency for studying and monitoring primary impacts caused by surface mining at low cost. It can also be used for studying atmospheric emissions and water pollution indirectly by monitoring green vegetation, an indicator of ecosystem health and conditions. Remote sensing has been used for detecting contamination, determining success in reclaiming open cast mined areas and for providing other relevant spatial data for assessing mining impact on the environment (Latifovic et al, 2005).

Ibrahim et al (2011) used the GIS coupling model to evaluate the ground movement and assess the damage to structures from Chinese coal mining. Woldai (2001) highlighted the importance of Mapping, monitoring and controlling the impact of mining on environment. The evaluation of ecological vulnerability in environmental impact assessment of Fuxin coal mining area was performed (Xueqin, 2013). Ecological vulnerability is the overall performance of the ecosystem change under mining development. The ecological vulnerability index was established synthetically reflecting ecological environmental status, ecological sensitivity and landscape spatial structure, including 9 indictors. The study area was plotted into five types of zone, i.e., appropriate exploitation zone, optimized exploitation zone, moderate exploitation zone, restrictive exploitation zone and forbidden exploitation zone.

Research was performed to estimate the damage risk to the buildings due to subsidence induced by the underground mining activity (Malinowska, 2010). In Polish mines, longwall mining method was used for coal extraction. Using the GIS tool, prediction was performed for possible risk to structural elements.

Environmental impacts due to nearly 200 abandoned mines (large surface mines and small scale underground mines) in Morocco has been studied (Khalil, 2014). For an abandoned Kettara mine site, the impact of the old mining activity through acid mine drainage is assessed by the design and elaboration of an environmental database.

Research on the use of GIS for mine reclamation planning was conducted at Korea for its application in the abandoned mine areas (Sung et al., 2012). A spatial database incorporating a topographical map, geological map, mine drift map, and borehole data was designed and utilized in GIS to examine distributed mine hazards that can damage the surrounding environment.

Research was conducted to assess the potential of the use of satellite data and to calibrate its content for monitoring the geochemistry of mining lakes. The surface waters of the post mining lakes in lignite mining area in Central Germany were sampled and analyzed for their physicochemical properties (Luise, 2011).

An effort was attempted towards the development of a geographic information system (GIS)-based monitoring and management system for underground mine safety in three levels as constructive safety, surveillance and maintenance, and emergency (Seda, 2009). The developed model integrates the database design and management to the monitoring system implementation which encompasses query and analysis operations with the help of web and desktop applications.

Spatial Decision Support System was developed for reclamation in an opencast coal mine to identify the best available solutions of reclamation problems (Chen and Li, 2008).

4. LAND USE LAND COVER (LULC) STUDIES

Land cover change can affect the ability of the land to sustain human activities. Land use land cover (LULC) inventories aid in planning of the land regeneration and mine closure activities. LULC information permits a better understanding of land utilization which is vital for developmental planning. This requires the availability of timely and reliable information on type, extent and spatial distribution of land use. This can be achieved from various satellite based high-resolution remote sensing data. Sustainability of the natural resources, i.e., land, water, air, forests, ecosystem, have been assessed to determine the limits of carrying capacity of each resources. There has been a growing need to evolve techniques and tools for prediction of environmental dangers.

Some of the remote sensing work focused on producing characteristic phenologies and monitoring surface dynamics for evaluating intra-annual deviations from baseline conditions, while other work was directed at mapping land cover distribution using various methods.

Jade & Sunita (2015) investigated the temporal changes in the feature classes identified as ridges, geological slopes, agriculture, vegetation, buildings and fallow land in the mining area of Khetri copper complex. Spatial attributes of these temporal changes were determined. The feature classes of vegetation, ridges and agriculture present a significant amount of variation over the five year period. Using band subtraction & NDVI assessment, the transformation of one feature into another was also investigated to understand the impact of mining activity on the landscape and land use. The long-term effects of land use/land cover (LULC) changes in Rajasthan state, India on land-atmosphere fluxes was studied (Shailesh, 2013). Multi-temporal satellite imagery has been used to study the dynamic ecological processes along the coastal wetland in the northern

Gulf Coast of Louisiana and Texas, USA (Bradley, 2014). The study provided an insight into the species–habitat relationships which may differ with dominant landscape characteristics. Latifovic et al (2005) applied the remote sensing to assess land cover change for Oil Sands Mining Development in Athabasca, Alta., Canada. The primary impact was assessed using an information extraction method applied to two LANDSAT scenes. Secondary assessment based on a key resources indicator (KRI), calculated using normalized difference vegetation index (NDVI measurements, air temperature and global radiation was performed for a time period from 1990 to 2002. A good agreement between the time series of inter-annual variations in NDVI and air temperature was observed. NDVI is proposed as a reliable indicator for assessing vegetation productivity and its sensitivity to changes in local conditions.

Researchers worked on understanding the change in channel morphology and its effect to alter surface water–groundwater interactions between the stream and the aquifer. Change detection studies have been deployed for the monitoring of artificial lake in Egypt from 1972 till 2008 (Elsayed et al., 2010). These changes were correlated with the surrounding geomorphic, structural, climatic and geologic factors. It involved estimating the water volume fluctuations in the study area. Research was performed with the objectives of identifying how patterns of habitat diversity and LCC can be predicted with geographic and remotely sensed data and to identify the relationship among spatial and temporal fluctuations, fragmentation and diversity in the post-mining landscape (Effah et al., 2008). Dynamically monitoring vegetation growth under coal exploitation stress was conducted on the satellite imagery (Lu et al., 2007).

Sarma (2005) applied the GIS tools for identifying, mapping and determining extent of vegetation cover in mine and unmined area. This study revealed the changes from dense forest to open forest in the Jaintia Hills District of Meghalaya due to anthropogenic activities. Using NDVI analysis, land cover mapping and change detection Matthew (2009) analysed the progression of disturbance caused by mining, and identifying and tracking reclamation sites and assessing the land cover changes. Chitade & Katyar (2010) used the GIS analysis to assess the LULC changes due to industrialization in the Wardha district.

5. LULC STUDIES IN THE COAL MINES

The objective of the land reclamation, restoration, monitoring is to assess the area of backfilled, plantation, OB dumps, social forestry, active mining area, settlements and water bodies, distribution of wasteland, agricultural land and forest land in the leasehold area of the project. This is an important step taken up for assessing the progressive status of mined land reclamation and for taking up remedial measures, if any, required for environmental protection. Land reclamation monitoring is carried out regularly on annual basis to assess the progressive status of land restoration, reclamation in the opencast mines.

South Eastern Coalfields Limited (SECL), the largest coal producing subsidiary of Coal India Limited with Coal production of 140.003 million tons during 2016-17 (SECL Performance Report, 2017). The opencast mines from the South Eastern Coalfields Limited (SECL) were studied. Based on classification of satellite imagery, the landscape was analyzed for three classes, viz., vegetation, backfilling and active mining (Reclamation Monitoring Reports, 2008 – 2013) (Uday et al, 2015). These classes are evaluated for their temporal changes from 2008 to 2013. The comparison between 2010 and 2011 revealed that the area of land reclamation, for both biological and technical reclamation, has increased from 59.86 Km^2 (Yr. 2010) to 64.00 Km^2 (Yr. 2011). Comparison between 2011 and 2012 revealed that the area under land reclamation has increased from 64.00 Km^2 (Yr. 2011) to 64.87 Km^2 (Yr. 2012). Comparison between 2012 and 2013 revealed that the area under land reclamation has increased from 64.87 Km^2 (Yr. 2012) to 66.96 Km^2 (Yr.2013).

The water bodies have also been given a serious view in its planning, storage and effective utilization. It was observed that over a series of years the land has been reclaimed in both technical and biological ways. There has been a progressive improvement in the total area reclaimed, plantation and backfilled area.

The statistics and scientific studies carried out based on the remote sensing and GIS tools point to the sensitiveness of the mine management in planning the mitigation measures, cautious scheduling of the

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production operations without hampering the environmental balance. Satellite imagery also point to the efforts in the conservation of vegetation cover and replenishment of the vitality of the mining landscape.

6. LULC STUDIES IN KHETRI COPPER COMPLEX MINES

Khetri is situated at the foothills of the Aravalli Range, which hosts copper mineralization, giving rise to a 80 km long metallogenetic province from Singhana in the north to Raghunathgarh in the south, popularly known as Khetri Copper Belt. It has mechanized underground mines namely 'Khetri' and 'Kolihan' (with a target of 3.1 million tonnes per annum for F.Y. 2016-2017), Beneficiation plant, and process plants [HCL Annual Report, 2016-2017]. Khetri mine is fraught with ground disturbances with its surface effects in the form of subsidence. Besides this, the mineral is processed on the surface processing facility, which generates sufficient land pollution in the form of tailings disposal. These effects also lead to after-effects leading to surface slope instabilities. With the help of satellite imagery (U.S.G.S. data of Landsat ETM and Landsat TM) of the area around Khetri Copper Complex mine the temporal changes in and around the mining industry were analyzed.

The study area of 472 km^2 surrounding the existing Copper mine was investigated and the changes were assessed across five years from 2006 to 2011. Using ArcGIS, the supervised classification was performed and it reveals the distribution of the six feature classes over the study area. In 2006, the largest areal cover is attributed to the fallow land which covers 39% and vegetation class which occupies 24% of the total study area. In 2011, of the total area the major components include Vegetation as 28%, Fallow land as 38%. Another major decrease is in the area occupied by Agriculture, which is 9.38 sq. km or 25% reduction from that in 2006. Band Subtraction reveals a more prominent impression of the tailings disposal in the band subtraction operations (Figure 1). The result of the inter-band operations were closely studied and then reclassified so as to highlight the immediate vicinity of the mines.

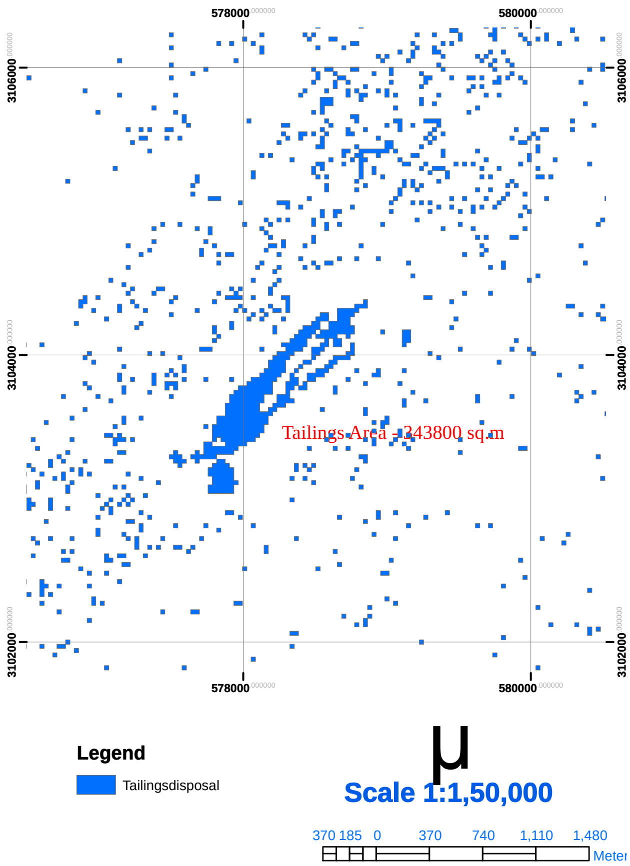

Figure 1: Tailings disposal area near the mines as observed from Band subtraction operations.

The image derivatives obtained from the raster and vector operations have been statistically processed for each of the feature classes in two different time domains (2006 and 2011). Based on the NDVI computations, it is found that the Vegetation area is 96 sq. km in 2006.

7. ENVIRONMENTAL MANAGEMENT ACTIVITIES

The mining activities are tuned to comply with all the environmental standards, like air, noise, water, social aspects, and general environment. AS a part of environmental management plan, the industry adopts several environmentally sound mining technologies and practices like Green Belt Development, Ground vibration control, Noise Control, Water drainage management, Air pollution control, Training, Safety Campaigns and Awareness. Green belt acts as buffer and shock absorber against dust, noise, fly rocks, etc. On either side of the haul road taller green belt is planted as mitigation measure besides its role of protection of the existing vegetation. Substantial afforestation measures are actively actuated. Improvised machinery has built-in silencers, mufflers and closed noise generating parts. Measures like confinement, machine maintenance, vibration absorbing accessories, and personnel protective aids are resorted in workplace. Under Water drainage management, garland drains are constructed; water is conserved in sumps, and used after treatment for consumption in various mining activities. Mitigation of Air pollution exercise involves containing the dispersion of dust at major sources, use of water sprinklers, precautionary measures like covered trucks during material transport, regular monitoring of ambient air quality of the mines area & surrounding villages. Besides this, the risks and good practices are prescribed to every employee through safety week, environment conservation campaigns, and skill development training.

8. CONCLUSION

Satellite Imagery operations and interpretation aids in the assessment of the environmental changes due to mining. The temporal changes have been brought out on the feature classes of vegetation, fallow land, agriculture, and others. Spatial attributes of these temporal changes have been determined. The classes of vegetation and agriculture present variations over the five year period. GIS analysis established a spatial transition of the changes in the feature classes. Thus, in the context of land rehabilitation, and mitigation of environmental impacts, the data repository through RS and GIS tool becomes highly valuable, precise and recursively deployed in temporal scales.

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