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Impacts of Coal mining: a Review of Methods and Parameters Used in India

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ABSTRACT

This review presents a systematic synthesis of the various methods and measures that have been used to investigate the effects of coal mining in India. A total of 87 peer-reviewed articles were collected for each year from 1970 to 2014 using a keyword based search. The articles compiled were analyzed and categorized according to the parameters addressed and the methodological approach adopted. Quantitative analyses were conducted to indicate the gap areas. Results indicate that research concerning air pollution, water pollution, land use pattern and environmental impacts are the best represented while soil, forest and human health are very poorly represented. Land cover change studies have experienced a rapid surge however studies on socio-economic and human health impacts are very few in number. majority of the studies mostly used laboratory as well as remote sensing based techniques. For a genuine and thorough interpretation of coal mining impacts, it is quite important to understand the direct as well as the far-reaching environmental and social consequences of coal mining. This article identifies the areas that have been well documented and primarily it emphasizes the areas that require further research in the Indian scenario.

Keywords: coal mining, environment, impacts, land use/land cover.

INTRODUCTION

Coal which is commonly called as the black gold of India contributes a major part to its commercial energy production and is widely used in the power industry to generate electricity. However, as compared to other fossil fuels, coal is more pollution intensive and the energy efficiency is very low[1]. Moreover its transportation and combustion have deleterious consequences which are borne by the Indian society as well as the people around the world. A number of these effects have been investigated by Indian researchers but the indirect and far reaching impacts have not been properly dealt with. The effects on the ecosystems, human health, biological diversity and water environment include some of the effects[2]. The removal and processing of coal at the mining site and its transportation to a power station distresses the environment[2].Various methods have been used to assess the impacts of coal on human health and the environment during its complete life cycle[3]. The external costs of coal mining and transportation have also been attempted in a number of international studies[4, 5, 6,7]. There is a bulk of research that have studied the cumulative and social impacts of mining[8,9], potential health impacts of burning beds[10], impact on women in Australia[11], cancer risks[12] as well as carbon and ecological footprints[13]. However, in India there is a lack of studies that have attempted to study and quantify the collective and progressive impacts of coal mining. The literature on the subsidiary impacts of coal mining and its contributions to greenhouse gas emissions is very little. This paper aims to

highlight the need for an advanced understanding of the quantifiable and measurable externalities of coal mining.

METHODOLOGY

A specific keyword-based search methodology was adopted so that all the papers collected are typical and indicative. Google scholar was the chosen search engine and custom search was done for every decade 1970-1980, 1981-1990, 1991-2000, 2001-2010 and 2011-2014. The initial search terms used were 'coal mining', 'coal mining and its impacts, Indian studies' and 'impact of coal mining'. The first 50 pages of Google Scholar were searched and the relevant papers were collected. The resulting literature that had relevance to the overall review was included in the paper count and distribution.

The papers gathered from keyword search were analyzed and categorized. The sub references of all the papers were also used. Only peer reviewed articles were considered and this led to a final selection of 87 studies (Table 1). Papers were analyzed based on the study design, the parameters addressed, and the techniques used. The objectives were to identify key issues addressed and the methods used but not detailed discussion of the results reported by each paper. Thirteen categories were developed from critical analyses of the individual studies as a way of sorting the research (**Table 1**). The individual papers were placed in the different categories by focussing on subject and topics that the research focused most strongly on.

RESULTS AND DISCUSSIONS

Trends in Research

There is an overall increasing and positive trend observed in the total volume of papers published as the years progressed by, as illustrated in Fig.1. There was no study reported for the years 1970 to 1980 on mining impacts. Few published studies were found between 1980 and 1990. The trend shows a drop in 2001-05 but then there is an increase in the number of relevant publications since 2006 onwards.

Environmental impacts, air quality, water quality and land use change studies are the only categories represented well in the research for all the decades since 1990s. In fact environmental impacts and air quality was the main focus of research in the years from 1986-1995. From 1996 onwards land use change studies and soil impact also gained importance. The land use change studies showed a fairly consistent presence from 2010 onwards. Fig. 1 illustrates how studies on the effects of

Table.1: Summary of collected papers

Sl. No.	Parameters addressed	No. of studies	Study design
1	Environmental Impacts	21	Laboratory/Analytical
2	Air Pollution, Dust emissions, Air quality	16	Laboratory/Analytical
3	Land Use/Land Cover, Land use pattern	15	Remote Sensing & GIS
4	Soil/Edaphic	9	Laboratory/Analytical
5	Water quality, Water Regime, Aquatic ecosystems	7	Laboratory/Analytical
6	Vegetation. Forests, Habitat Diversity	5	Remote Sensing & GIS
7	Human health, Settlement Risk	4	Socio-economic surveys
8	Acid mine drainage	3	Laboratory/Analytical
9	Micro-biological studies	1	Laboratory/Analytical
10	Sustainable development	1	Analytical
11	Flood disaster	1	Remote Sensing & GIS
12	Socio-economic impact	1	Socio-economic surveys
13	Agriculture impact	1	Laboratory/Analytical

vegetation are absent until 1997, but remain fairly insignificant with only a few studies in 1998, 2006, 2009 and 2014.

Research focussing on impacts concerning air pollution, water pollution, land use pattern and environmental impacts are the most well represented while studies focusing on soil, forest and human health are less represented. Land use change studies have experienced a rapid increase in representation. Studies regarding socio-economic impacts are few in number. Also majority of studies used laboratory based analytical methods while land use pattern and forests impact studies are based on remote sensing based analysis.

Environmental impact studies saw a fairly consistent distribution throughout all the years. In fact it is significantly greater represented than every other research category. Studies on air quality and water quality also appear to be fairly consistent as shown in Fig. 2. However, Table 1 shows that air quality studies have a stronger representation than water quality and all other categories except land use change. Effects on the forests and human health are poorly represented. Studies looking at agriculture, socio-economic conditions, micro-biological organism are also very poorly represented within the literature. Soil impact studies papers were significantly greater than papers on water quality, forest and human health but lower in representation than air quality and land use change studies (Table 1).

Key issues addressed

Environmental Impact Assessments

A large number of researchers have focussed on estimating the environmental impacts and total ecosystem impacts[14, 15, 16,17,18,19]. Ghose (1989)[20] studied the impacts of Jharia coalfield mining and calculated an overall impact index with high negative values for land use and related features. Dasgupta *et al* (2002)[21] addressed the impacts from an ecological perspective while Ghosh, 1991[22] and Vagholikarin 2003[23] studied the overall environmental impacts of underground mining. The environmental impacts of open cast mining operations have been addressed[24, 25, 26]. Ahmad *et al* (2014)[27] studied those environmental parameters which were of special concern to the health of population while Asokan *et al* (2005)[28] studied the environmental implications of coal combustion residues. The business of mining irreversibly ruins the natural environment as well as the nearby communities. It is therefore necessary that we have a complete knowledge of all the mining related activities which lead to one or more problems with regards to the environment [29, 30].

Air Quality

The release of toxic gases like methane, nitrogen oxides and sulphur dioxide pollutes the

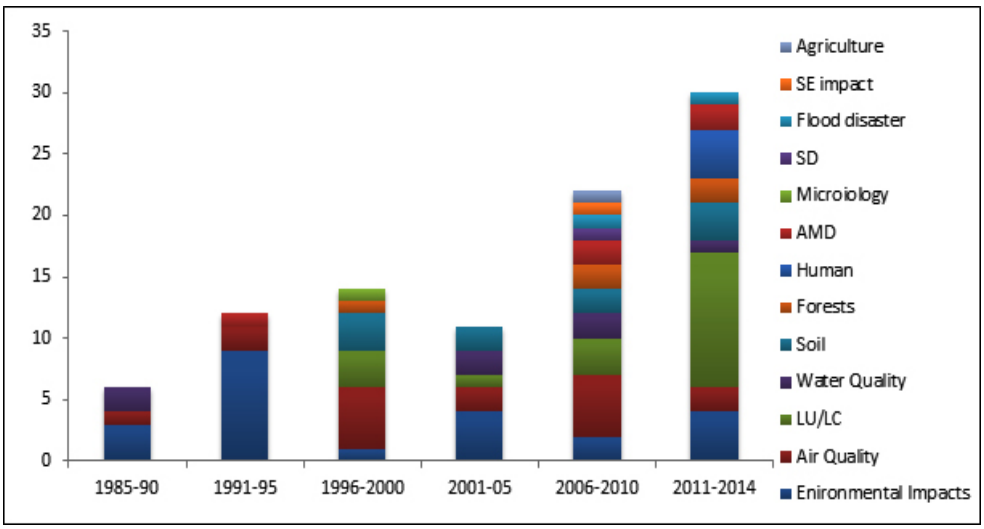

Fig. 1: Total distribution of paper counts from 1986-2014. Note: SE = socio-economic, SD = sustainable development, AMD = acid mine drainage and LU/LC = land use/land cover.

surrounding air and hence deteriorate the air quality. These are also the major gases that contribute to global green house gas emissions and overall warming of the planet. There are a number of studies since 1989[31-41] on the air quality impact of the coal mining operations, most of them reported by Ghose and Majee[42-52]. The surface mining operations like hauling and transportation generate huge quantity of dust of varying sizes[52] which are the major sources of air pollution in the surface coal mining regions. These dust particles and gaseous pollutants when released into the atmosphere pose an immediate and potential threats to the mine workers as well as the nearby agriculture areas, cattle, livestock and the population. The harmful effects of these pollutants may be aggravated by the prevailing meteorological conditions of the region[53]. The overburden dumps and coal gangue sometimes ignite spontaneously releasing unwanted gases into the atmosphere which in turn affects the air quality to considerable limits.

Land use/Land cover

A major chunk of the studies have been reported by various workers[18, 20, 53, 54, 55] regarding the effects of mining on the landscape. Prakash and Gupta (1998) and Rathore and Wright (1993)[56, 57] stated that mining was correlated to the changes in land use. Mining and its related industries are disastrous and unfavourable to the land use pattern[55], especially surface mining has a profound impact on the pattern land use during both the pre and post mining operations. Since 2010 studies on land use and land cover changes dominated the research on coal mining. All the studies noted a marked decline in the forest cover[55, 58]due to unregulated mining practices[59]and deforestation[60, 61]. A study by Kumar and Pandey[62]revealed that an increase in coal mining leads to changes in land-use primarily by expending agriculture and forested areas. A detailed knowledge of land use practices is essential to understand the land use pattern, its dynamics and implications for the management and planning of land, as well as policy making and infrastructure developmental initiatives.

Water Quality

The earliest study on the effects of surface coal mining operations on the water quality was reported[63, 64]. A study on water quality effects of coal mining in Jaintia Hills in Meghalaya[65]revealed that coal mining has increased the toxicity level to such an extent that the water is completely unfit for agriculture and human consumption, and even highly toxic to the native flora and fauna. As a result the water bodies that were earlier beaming with life and biodiversity have now been deprived of aquatic life and no more contribute to their role in the ecosystem as life supporters. The degraded water now comprised of high concentrations of sulphate ions, toxic heavy

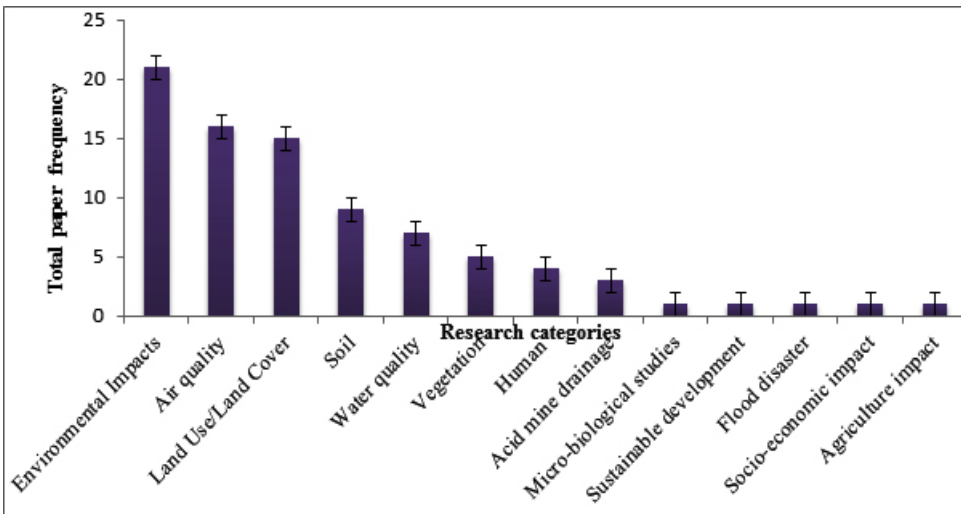

Fig. 2: Total volume of papers for each category published from 2007-2014. Bars indicate the maximum and minimum amount of papers in a given year 2015.

metals, high biological oxygen demand (BOD) and high electrical conductivity. According to Gaurav and Khan (2014)[66] who analysed the surface and ground water of monsoon and post monsoon season of Dakra-Ranchi mining project, mining areas suffer from highly contaminated water with the concentration of many parameters like turbidity, magnesium, hardness and alkalinity way above the specified and allowable limits in both the seasons. There are a few latest studies on the evaluation of ground water quality[67-69].

Land Degradation

The surface coal mining operations and all their associated activities degrade the land to considerable limits. The land damage caused due to coal mining was studied[70]. Large areas of land are excavated during open cast mining operations in order to extract mineral ore[59]. Significant amounts of forest is lost along with the rich top soil during pre-mining overburden removal and replaced by undesirable waste. This overburden is waste for the industry and hence it is usually dumped and collected within the mining area, and also on public land sometimes. The overburden material is quite unstable and leads to deleterious impacts and degradation of land in the vicinity. The degraded lands thus suffer from problems of changing drainage patterns due to changes in topography, landslides and soil erosion. Akram and Khan[71]did a comparative analysis and observed that dense forest is transformed into open forest, scrubland

Table 2: Remote Sensing and GIS based studies

Reference	Region	Mining type	Aspect
Rathore, 1993		Surface	Environmental Impact
Majumdar and Sarkar, 1994	Singrauli coalfiled		Impact on physical and cultural environment
Prakash and Gupta, 1998	Jharia Coalfield	Underground and	Land change dynamics
Sikdaret al , 2004	Raniganj Coalfield area	open-cast	Land change dynamics and ground water quality
Joshi et al , 2006	Korba, Chhattisgarh		Deforestation
Malaviyaet al , 2010	Bokaro, Jharkhand		Land change dynamics and habitat diversity
Katpatal and Patil, 2010	Erai watershed, India	Open-cast	Flood disaster
Singh et al , 2010	Angul-Talcher, Orissa	Open-cast	Land use pattern
Panwaret al , 2011	Angul-Talcher, Orissa	Open-cast	Land change dynamics
Sharma and Kushwaha, 2011	Jaintia Hills, Meghalaya	Open-cast	Land change dynamics
Akram and Khan, 2012	Singrauli, MP	Open-cast	Land change dynamics
Khan and Akram, 2012	Singrauli, MP	Open-cast	Land change dynamics
Pavan Kumar et al , 2012	Jharia Coalfield	Open-cast	Settlement Risk
Singh et al , 2013	Jharia Coalfield	Open-cast	Land use pattern
Areendran, 2013	Singrauli, MP	Open-cast	Land change dynamics
Kumar and Pandey, 2013	South Karanpura Coalfields, Jharkhand	Open-cast	Land change dynamics
Mondolet al , 2013	Keonjhar District, Orissa		Land use pattern, Environmental Impacts
Gaurav and Khan, 2014	North Karanpura Area of Central Coalfields Limited, Dakra, Ranchi	Open-cast	Water Quality and Vegetation
Mondalet al , 2014	Keonjhar District, Orissa	Open-cast	Environmental Impacts
Sekhar and Sethy, 2014	Keonjhar District, Orissa	Open-cast	Impacts on forest

Table 3: Direct drivers of land use changes due to mining and their corresponding effects

	Impacts	Implications	Gaps
Direct Drivers			
Habitat change	Conversion of forests	Effect on existing stores of vegetation carbon and hence green-house gas emissions	Needs to be addressed
	Conversion of agricultural land	Effect on soil carbon stores and GHG	Needs to be addressed
	Urbanization and industrialization	Effect on the albedo, shade, shelter and local climate like temperature and humidity	Needs to be addressed
Land use change	Dumping of overburden materials	Land degradation	Addressed
Environmental Pollution (Air)	Emissions of gaseous pollutants	Deposition of dust on surrounding vegetation, changes in local climate additive on global warming	Addressed
Environmental Pollution (Water)	Nutrient and chemical inputs	Effect on soil and aquatic bodies,	Addressed
Environmental Pollution (Waste dumping)		Degradation of aquatic ecosystems	Addressed
Indirect Drivers			
Fossil fuel burning	Emission of green-house gas carbon dioxide	Contribution to global warming	Needs to be addressed
Coal Bed methane	Emission of green-house gas Methane	Contribution to global warming	Needs to be addressed
New roads and pipeline routes	Primary remote forest become more easily accessible	Increased timber harvesting, wildlife conflicts, and forest clearing for human habitations	
Land Use Change	Changes in surface reflectance – Albedo	Influence on global warming	Needs to be addressed
Polluted Aquatic bodies	Effects on the livestock and animals		
Changes in topography, hydrological patterns, soil erosion and increased accessibility to fossil locations.	Impacts to the paleontological resources		

Disturbed and stockpiles soils and compacted areas	Colonization by invasive species	Impact on bio-diversity and native species	Needs to be addressed
Accidental ignition of the coal reserves- Coal fires	Wasteful burning of resource along with resulting Fossil fuel emissions	Contribution to global warming	Needs to be addressed

and quarries due to the extension of mining areas. There is an increase in open scrubland, excavated dumps, and human settlements while there is a decrease in agricultural lands which are converted into wasteland. The impact on soil has been studied by many workers like[72-77]. Ghose (2004)[78] reported the changes in soil fertility due to open cast mining operations in eastern coalfields. Surface mines cause more pollution as they produce large amounts of waste in comparison of the underground mines.

Bio-diversity

The first and direct impact of mining operations in forested areas is the eviction of forests which alters the food availabilities and wildlife habitat. Kumar and Pandey (2013)[62] noticed that in some of the coal mines, the forest cover is completely lost to the mining enterprises. On the other hand the existing forests were subjected to human disturbances of various kinds like tree felling for fuel-wood requirement, expansion of agriculture into the forest area and diminished renewal of flora due to a polluted environment. According to Gaurav and Khan (2014)[66], large scale mining causes massive deforestation and conversion of forested areas into non-forest areas. The coal dust also settles on the leaves of plants which affects the growth of plants. Charak *et al* (2009)[79] studied the impact of coal mines on ecology like, species richness and abundance around the Moghla Coal mines in Kalakote area of Jammu and Kashmir. The study revealed that the open coal mining activities affect both the qualitative as well as the quantitative parameters of species distribution. Therefore on a large scale, the mining operations change the biodiversity by changing the species composition. Malviya *et al* (2010)[59] studied the habitat diversity in the coal mining areas of Bokaro, Jharkhand. He concluded that while intact forests may be resistant to the impacts of mining and development, fragmented forests are less likely to withstand such invasions. Yet only a few studies have been reported in this aspect. The indirect infrastructure developmental activities like construction of roads and new pipelines routes lead to habitat fragmentation and open up the remote areas for accessibility. A study[94] concluded that degradation of forest is one of the major externalities of open cast mining which is yet to be addressed properly and therefore needs a thorough attention in the upcoming days.

Acid Mine Drainage

Acid mine drainage is one of the most significant and severe environmental problems associated with the coal mining industry. The main cause of acid mine drainage is the occurrence of pyrite and sulphide minerals in the coal seam rocks. During mining coal beds and surrounding strata are disrupted. Consequently, these sulphide minerals get exposed to air and mine water and the resultant oxidation and hydrolysis leads to the generation of acid mine drainage. Equeenudin *et al*, 2010[80] reported a detailed geochemical characterization of acid mine drainage and its impact on the water quality of various creeks, rivers and groundwater in the Makum coalfield area. A review article[81]describes the general chemistry of acid mine drainage generation and its impact on the environment. Jamal *et al* (1991)[82] had reported on the acid mine drainage component of open cast coal mining operations.

Health and Society

Very few studies have been reported on the societal and human health effects of coal mining. Kumar *et al.* (2012)[83] used high resolution satellite data to study the area of settlement at risk in the Jharia coalfields. He concluded that a majority of the settlement areas are at high risk due to mine fires and subsidence of land. Moreover, surface mining poses a potential threat as there is danger from the frequent mine fires and unstable rocks subsequently lowering the land productivity.

The earliest study reported was on the impact on physical and cultural environment [84, 85, 86]. The mine workers are constantly exposed to high

concentrations of dust and gases along with and elevated noise levels thus posing a threat to their life. Other than this they are also prone to respiratory diseases due to the suspended particulate matters in the air created by mining activities like blasting and drilling operations. Some activities like drilling, blasting, loading-unloading of materials, overburden. The effects of these particulates matter might vary depending on the exposure time and the concentration of the particles in the air[87]. The study done by Singh *et al* 2010[93] concluded that the mine workers suffer from various types of skin and respiratory problems which takes a toll on their overall health, living standards and working capability. Also the high noise levels and vibrations tend to influence the wildlife more than the human[55]. Health of the local population is also impacted due to contamination from leakages of chemicals and vibration from blasting/drilling operations[54]. Senapaty and Behera (2012)[85]observed that in IB-valley coalfield of Odisha, India the coal as well as the ground water has high levels of trace elements , India. He also studies the probable implications of these for human health aspects.

Others

Amongst other issues that have been addressed include micro-biological studies, sustainable development, flood disaster and impact on agriculture. Kundu and Ghose (1997)[72] studied the microbiological impact of coal mining while Chikattur *et al* (2009)[88] studied the different aspects of mining sector in India with a view to promoting sustainable development. An analysis was conducted to investigate how coal mining related processes like over burden dumps caused flooding in the Erai watershed of India using spatial analysis[89]. The agricultural productivity nearby coal mining areas of Orissa was also studied by Mishra (2008)[90] and the study revealed that the agricultural productivity is reduced significantly as a result of mining. They also observed that people involved in agriculture changed their occupation to works associated with mining.

Methods used for evaluating impact of coal mining

Analytical and Laboratory

There are two wide groups of methods that are used: (1) the analytical and laboratory based and (2) the remote sensing based. Majority of the earlier studies used analytical and laboratory based methods while the later researches are more focussed on remote sensing based assessments.

Remote Sensing

Remote sensing and Geographic Information Systems (GIS) are the most reliable techniques for identifying and estimating the magnitude of deforestation and degradation caused by mining activity and studying the pattern of landscape dynamics over time[91]. The satellite based data provide a perpetual and genuine means of assessing the land-use patterns which can be re-used for verification and reassessment of impact of mines[91]. Most of the mines are located at in-accessible and hostile terrain so remote sensing has a tremendous application for collecting information about the mining impacts as well as rapid spatial and temporal monitoring[92]. There are a lot of studies that have attempted to utilize satellite data and spatial analysis to detect temporal land use changes. These studies are summarized in Table 2.

Socio-economic surveys

During the last century, mining related activities have brought about significant health risk and socio-ecological instabilities. Singh and Pal[93] conducted field surveys in some selected mine areas of Jhansi district. They used structured questionnaires to collect information about the status of health and socio-economic impacts from random mine workers and the family heads living in the mine areas.

Challenges and Future Research

Addressing the drivers of change

Coal mining projects are the main causative factors behind both direct as well as indirect land use changes. The direct changes/direct drivers refers to changes in actual land used for the coal mining as shown in **Table 3** whereas the indirect changes/ indirect drivers includes the changes occurring at another place due to mining of coal at one place. The indirect changes like road networks and construction of human habitations are often responsible for the wide-ranging effects of coal mining. On the other hand, the direct changes unambiguously affect the entire ecosystem as a whole[94]. The indirect drivers are quite dispersed and they function by influencing

the other direct drivers. So far very few researches have addressed this issue. There are a number of direct and indirect drivers that can affect the land use changes caused by coal extraction and processing as summarized in **Table 3**.

Quantitative evaluation of impacts

Fossil fuels resources like coal are the largest and the easiest to access and their fast depletion increases the ecological impacts of fossil fuel mining. More usage of land and water, more waste production and increasing energy inputs are required for a constant fossil fuel production. It is relevant to consider what a given amount of fossil energy source can cause to the environment and ecosystem. The increasing ecological and environmental impact of a given amount of useful fossil fuel energy is a relevant consideration in assessing alternative energy strategies[94]. So far, very less number of researches has been attempted on this and needs to be studied more exclusively related to each indirect aspect shown in Table 3. There is a lack of articles that have assessed the superficial costs of coal mining and its transportation to power station quantitatively.

Modeling for mining impact

There are many studies on the effect mechanism of the mining related land use drivers via biogeochemical and bio-geophysical process, while there is less research that involves modeling processes; hence it is necessary to pay more attention to how mining effects operate considering both bio-geochemical and bio-geophysical effects through modeling and simulation. There is also need to undertake scenario analyses and predictive modeling so as to develop effective mining and mitigation strategies.

Rate of land use changes

The rate of changes of different land use sectors over the years has not been addressed in many of the studies. There is one study that attempts to evaluate the rate of land use change for Shurugwi district for the time period of 1990-2009. This study also tried to explore the intrinsic geographical changes, magnitude of change, and discerning the factors responsible for the changes. Relatively few studies attempt to record the land change dynamics using satellite data combined with spatial analysis.

Climate change in mining areas

The power plants using coal as the fuel source are the biggest emitters of carbon dioxide (CO_2). About one third of all carbon dioxide emissions come from burning coal. Hence, coal is the single largest threat for climate and planet earth. The greenhouse gases (GHGs) associated with transportation of coal includes CO_2, CH_4 and N_2O (nitrous oxide). Methane (CH_4) is primary GHG related to coal mining that is released when coal seams are cut for coal extraction. The environmental impact assessments should include a quantitative estimate of emissions from machines and vehicles that will be needed during the life of the mining project. There is a need for studies that focus on the mining induced emissions of green house gases, global warming and climate change.

Sustainable Development

The economic benefits arising from coal mining are very less when compared to the losses incurred to the nature and ecosystem[95]. The society and environment are highly neglected by the mining enterprises while economy is often given more priority. Therefore a balance is essential between these three interconnected factors to achieve sustainable development. Mining industries must be responsive to various sustainability challenges and address their sustainability concerns[96]. This requires extensive and detailed research into the sustainability component of coal mining.

CONCLUSIONS

The trends illustrated by reviewing the top cited literature display how the volume of research has been increasing with relative consistency since1986. Despite the gaps, the research has undoubtedly brought attention to the potential and realized threats that coal mining poses. Majority of the studies are focussed on the environmental parameters that are directly impacted by mining. The studies have not looked at the far reaching impacts and a land use element that might be indirectly impacted. There is no study which assesses the quantitative aspects of impacts, linkages between the different drivers and the quantitative estimates of impact of one driver on the other drivers. The limitations of the existing studies are that there is a lack of an integrated approach and interlinked changes. There is an absence of modelling studies

and its implications due to mining. The vulnerability of the forests and various land use sectors to the global climate change due to mining contributions also need to be addressed so as to build resilience to a changing climate and develop strategies for mitigation and adaptation.

As per IPCC 2007[97], coal continues to be one of the leading and long-term sources of global energy supply and will continue to be so until the naturally available economic resources are existent. So, the direct, secondary and cumulative impacts on biodiversity should be assessed throughout the process of mining.

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