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Coal mining in northeast India: an overview of environmental issues and treatment approaches

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Abstract Northeast India has a good deposit of sub-bituminous tertiary coal. The northeast Indian coals have unusual physico-chemical characteristics such as high sulfur, volatile matter and vitrinite content, and low ash content. In addition, many environmental sensitive organic and mineral bound elements such as Fe, Mg, Bi, Al, V, Cu, Cd, Ni, Pb, and Mn etc. remain enriched in these coals. Such characteristics are associated with more severe environmental impacts due to mining and its utilization in coal based industries. Environmental challenges include large scale landscape damage, soil erosion, loss of forest ecosystem and wildlife habitat, air, water and soil pollution. Several physical and chemical methods are reported in literature for the removal of mineral matter, total sulfur and different forms of sulfur from high sulfur coal in northeast India. This paper may help different researchers and stakeholders to understand current state of research in the field. Initiatives may be taken towards sustainable use of coal resources by adopting innovative clean technologies and by implementing effective control measures and regulatory policies.

Keywords Northeast India · Sub-bituminous coal · Environmental issues · Innovative technologies · Management and regulatory policies

1 Introduction

Coal is the most important and abundant fossil fuel in India. With increased population, growing economy and a quest for improved quality of life, energy demand in India is rising. Mining is not only fulfilling the increasing energy demand of industry, but also plays an important role in the economic development of the country (Chaulya and Chakraborty 1995). Power sector is the largest consumers of coal followed by iron, steel and cement segments in the last four decades (Fig. 1). Other smaller consumers include fertilizer, textile (including jute and jute products), paper and the brick industry. Coal mining and its utilization is associated with substantial environmental challenges as it creates significant and often irreversible impacts upon the terrestrial and aquatic environment.

Open cast or surface mining is dominant in India and it not only alters the nature of groundwater–surface water interactions but also contributes to major air pollutants to the atmosphere and results in dramatic changes in the landscape. Most coal mining districts in India have been declared as critically polluted areas (CPAs) by MoEF in 2009 (CSE 2012).

In northeast India, coal mining was initiated by Medlicott in 1869 and 1874 (Sarma 2005a, b). The Cenozoic coals in the northeast states of India with its unusual physico-chemical characteristics have been playing an important role in the Indian economy for the last few decades (Baruah 2009; Saikia et al. 2014a). Due to its unique properties and consequent environmental issues,

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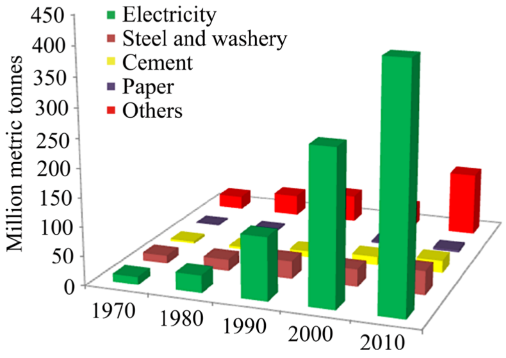

Fig. 1 Consumption of raw coal by different industries in India. *Source*: India Energy Book 2012

coals in northeast India draw special attention (Zamuda and Sharpe 2007; Saikia et al. 2014a).

The main objective of this paper is to summarize coal characteristics and associated environmental issues in northeast India. In addition, this paper also reviews the current state of research in the field of various treatment approaches to reduce environmental impacts of coal.

2 Coal distribution and its characteristics in northeast India

As on April 2014, India's inventory of coal resource was 300 Billion Tons (BT) comprising of: Proven—125 BT; Indicated—142 BT and Inferred—32 BT (Ministry of Coal 2014). Northeast India contributes 105 Million Tons (MT) of the Gondwana coal and 1492 MT of tertiary coal reserves. Meghalaya and Assam in northeast India contain 73 % of the total tertiary coal reserves. Nagaland and Arunachal Pradesh contribute 21 % and 6 % of the total tertiary coal reserves, respectively. Coal inventory of northeast India is given in Table 1.

Table 1 Northeast India's coal inventory of Gondwana and tertiary coal in million tones (Ministry of coal, India as on April 1, 2014)

Coalfield	State	Proved	Indicated	Inferred	Total
Gondwana	Assam	0	4	0	4
	Sikkim	0	58	43	101
	Total	0	62	43	105
Tertiary	Arunachal Pradesh	31	40	19	90
	Assam	465	43	3	511
	Meghalaya	89	17	471	577
	Nagaland	9	0	307	316
Total		594	99	799	1492

Source Ministry of coal (2014)

Sub-bituminous tertiary coal of northeast India was deposited under the influence of marine environment (Rajarathnam et al. 1996). These coals have high sulfur and low ash content, with high organic sulfur, due to the influence of marine sources during diagenesis (Chandra et al. 1983; Singh and Singh 2000; Ward et al. 2007; Widodo et al. 2010). Coal can be termed as low sulfur (<1 % sulfur content), medium sulfur (1 %–<3 % sulfur content) and high sulfur coals (>3 % sulfur content) based on their sulfur contents (Chou 2012). In addition to high sulfur content, northeastern coals have a high content of volatile matter and vitrinite contents, yielding double the amount of tar in comparison to other Indian coals. Mining of these coals generates a large volume of waste materials. These coals generally contain 2 %–8 % total sulfur, where 75 %–90 % is of organic sulfur, while the rest is in inorganic form viz. sulfate and pyritic sulfur (Baruah and Khare 2007a). Ledo and Baragolai coal of Makum coalfield, Assam, India contains 28.2 % and 21.5 % of inorganic and 71.7 % and 78.5 % of organic sulfur, respectively (Baruah et al. 2006). In a study, proximate and ultimate analysis of coal collected from Makum coalfield, Assam showed 3.31 %, 2.95 % and 2.16 % of ash content, total sulfur and organic sulfur, respectively (Saikia et al. 2014a). The volatile matter and vitrinite content of the Makum coalfield, Assam were 42.3 % and around 93 %, respectively (Saikia et al. 2014a). Total sulfur of Namchik coalfield, Arunachal Pradesh ranged 1.23 %–4.84 %, with organic sulfur constituting ~41 %–74 % of total sulfur and volatile matter ranged 41.8 %–46.6 % (Chandra et al. 1984). Similarly, in Bapung coals of Jaintia Hills, Meghalaya, organic sulfur was more abundant among the different sulfur species constituting an average 62 % of organic sulfur of the total sulfur content of 4.59 % in it (Ahmed and Rahim 1996). Total sulfur sometimes exceeding 7 wt% out of which the organic sulfur content accounts for about 75 % and the rest is inorganic sulfur. Tiru valley coals of Nagaland, India are sub-bituminous to bituminous-D in rank characterized by low to medium moisture (4 %–7 %), moderately high volatile matter content (22 % and 42 %) and high sulfur (5 %–11 %) content (Singh et al. 2012a, b). Ash, volatile matter and total sulfur content of Northern Mongchen and Moulong Kimong coalfields, Nagaland, India ranged 2.01 %–19.5 %, 34.9 %–44.8 % and 3.23 %–5.21 %, respectively (Das et al. 2015).

In addition to high sulfur and volatile matter, and low ash content of northeast coal, many environmental sensitive organic and mineral bound elements remain enriched in these coals that can cause air, water and land pollution. Sub-bituminous coals of Assam obtained from Makum coalfield showed that Fe, Co, Ni, Cu and Zn are significantly mineral bound, Mg, Ca and Mn are organic bound, while Cd is 50 % bound to either organic or mineral matter (Baruah et al. 2003). The aqueous leaching of these coals showed their tendency to atmospheric weathering and highly acidic water formed during the leaching process enhanced the mobilization of associated trace and heavy metals (Fe, Mg, Bi, Al, V, Cu, Cd, Ni, Pb, and Mn) above the regulatory levels (Baruah et al. 2006). Element concentrations such as Cr, Mn, Ni, Cu, Zn, As and Pb in coals obtained from Makum coalfield, Assam were 5, 23, 5, 2, 27, 1 and 4 mg/kg, respectively. Concentrations of these elements in coals from Moulong Kimong coalfield, Nagaland were 4, 2289, 3, 2, 49, 2 and 1 mg/kg, respectively (Saikia et al. 2014a). Study further indicated that many of these elements were associated with hematite, magnetite, and goethite in the coals.

3 Environmental issues associated with coal mining and its utilization in the region

Unscientific mining of minerals poses a serious threat to the environment, resulting in reduction of forest cover and loss of biodiversity, soil erosion and pollution of air, water and land. The primitive and unscientific ‘rat-hole’ method of mining adopted by private operators and related activities have caused large-scale environmental degradation and severe ecosystem destruction in Meghalaya (Swer and Singh 2003, 2004; Sarma 2005a, b). Large scale denudation of forest cover, scarcity of water, air and water pollution, degradation of soil and agricultural lands, land subsidence, haphazard dumping of coal and overburden are some of the conspicuous environmental implications of coal mining in north eastern coal mines of Meghalaya, India (Swer and Singh 2004). Based on a study in the Nokrek Biosphere Reserve in Meghalaya, India, it is revealed that coal mining has adversely affected the vegetation and the density of trees, shrubs and herbs in mined areas (Sarma and Barik 2011).

The mining and cleaning of coal at local processing sites creates large quantities of ambient particulate matter (Ghose and Banerjee 1995; Ghose and Majee 2000). Opencast mining operations contribute major air pollutants to the atmosphere and are responsible for environmental degradation by deteriorating the air quality in respect to dust, fine coal particles and other gaseous pollutants (Mukhopadhyay et al. 2010). The major sources of air pollution in coal mining area include: drilling and blasting, loading and unloading of coal and overburden, movements of heavy vehicles on haul roads, dragline operations, crushing of coal in feeder breakers, presence of fire, exposed pit faces, wind erosion and exhaust of heavy earthmover machinery (Nair and Sinha 1987; Ghose and Majee 2007; Huertas et al. 2011). According to Ghose and Banerjee (1997), air pollution caused by washeries is more acute than any other coal processing operations.

Based on a report on ambient air quality around northeastern coalmines in Margherita, Assam, the maximum daily average values of SPM (Suspended Particulate Matter), RPM (Respirable Particulate Matter), SO_2 and NO_x were found to be 214, 60, 25 and 52 μg/m^3, respectively (Envirocon 2010). Except for SPM, all other values were within CPCB guidelines (CPCB 2009). Atmospheric concentration of gaseous NH_3, SO_2 and NO_2 released from the mining activities in open cast mine area of Tirap colliery, Margherita (Assam), ranged between 4.7–40.03, 1.47–6.14, and 1.92–2.40 μg/m^3, respectively, and particulate NH_4^+ in PM_{10} and $PM_{2.5}$ ranged between 0.02–0.07 and 0.008–0.03 μ g/m^3, respectively (Sarmah et al. 2012). The study further suggested that low emission and deposition of NO_x and SO_x prevents the greater formation of acidic species due to neutralization with NH_4^+. Source apportionment of $PM_{2.5}$ levels at the suburban site of northeast India (Khare and Baruah 2010) showed that largest contribution to aerosol mass in $PM_{2.5}$ is from crustal sources (38 %) followed by coal combustion (26 %), industrial and vehicular emissions (19 %), wood burning (9 %) and secondary aerosol formation (8 %). Among different elements, emissons of Te, Fe, Mn, Cd, Sn and Sb were related to coal burning (Khare and Baruah 2010).

Coke industry is one of the major coal utilization industries in northeast India. To assess the impact of coke oven burning high sulfur and volatile matter containing coal on ambient air quality, levels of SO_2, $PM_{2.5}$ and trace metals were investigated (Khare and Baruah 2011). The study showed that total emissions of $PM_{2.5}$, total carbon (TC), black carbon (BC) and organic carbon (OC) ranged between 72–306, 49–217, 0.71–2.9 and 48–214 t/year, respectively and the concentration of trace metals was in the decreasing order as: $Te > Mn \sim V > Cr > Co > Mo > Cu > Zn \sim Sb > Sn > Cd \sim Ni > As > Se > Hg$. The study further indicated that emission rates of metals were dependent on the volatility of the metals, condition of coke ovens and rank of coal (Khare and Baruah 2011).

In addition to air pollution, problems of AMD (Acid Mine Drainage) are intensely localized in the coalfields of northeast India, where ecology of the surrounding area is badly disrupted. The rejects and coals dumped near the pit entrance are exposed to the environment. Being highly enriched with sulfur, pyrite present in these materials is oxidized and hydrolysed and therefore is well known for the generation of AMD (Tiwary 2001; Baruah et al. 2005, 2006; Baruah 2009; Baruah and Khare 2007a). Metals concentrations in mine water in India and the world is shown in Table 2. As it is visible, metals such as Fe, Cu, Mn, Zn, Ni and Pb in mine water of northeast India (Jaintia and Makum) showed higher concentrations as compared to other mining sites in India. Zn and Pb showed the

Table 2 Metal contents in mine water (μg/L) in few coal mines in northeast India, India and the world

Parameter	Fe	Cu	Mn	As	Zn	Ni	Pb	Cr	Cd	References
Jaintia coalfield (Meghalaya, India)	118,400	320	4070	–	4220	1080	430	60	30	Sahoo et al. (2012)
Jharia coalfield (Jharkhand, India)	423	32.3	136	3.4	106.1	17.6	14.9	8.1		Singh et al. (2009)
Raniganj (West Bengal, India)	329	18.8	39.4	10.06	60	45.6	22.6	44.6		Singh et al. (2009)
West Bokaro coalfields (Jharkhand, India)	652	46	1431	7.21	194	154	34.3	81.2		Singh et al. (2009)
Makum (Assam, India)	105,300	310	10,200		1530	3120	270	56	35	Equeenuddin et al. (2010)
Karnen (Iran)	192,500	350	30,900		2070	1060	180	850	18	Shahabpour et al. (2005)
Dogye coalmine (Korea)	176,300	430	8360		2120					Chon and Hwang (2000)

maximum concentrations in Jaintia coalfield of Meghalaya, northeast India and Ni showed the maximum level in Makum coalfield of Assam. Such high concentrations of metals in these sites can be attributed to higher leaching under acidic conditions in these coalfields. However, elemental contents in leachate water are controlled by three factors: the oxidation rate of pyrite, the acidity of the leachate water and the mineralogy of the rejects (Baruah and Khare 2010). Further, it depends on the element content in the coal. Concentration of toxic elements present in northeastern and other coals in India is shown in Table 3. Toxic metal such as Cd showed the maximum level in Jaintia coal of Meghalaya, northeast India. In a study on elemental leaching of Meghalaya coals, elements such as Al, P, S, K, Ti, Cr, Co, Zn showed negative correlations with pH (Baruah and Khare 2010).The release of Al, Si, P, Cl, K, Ti, Mn, Co and Ni concentrations in the leachates depends on pyrite oxidation and dissolution (Yue and Zhao 2008), whereas Cd, Sn, Sb and Te contents in the leachates are mainly controlled by adsorption on Fe hydroxides, which is indirectly influenced by pH. The concentrations of trace and potentially harmful elements (Sb, As, Cd, Cr, Co, Cu, Pb, Mn, Ni, V, and Zn) in the Meghalaya coals mine rejects ranged (mg/kg): 11.1–12.6, 1.3–25.9, 5–5.1, 259–361, 20.9–22, 23.6–32.9, 98–149, 87–104, 36.4–58, 50–55 and 35.8–55, respectively, and among these Sb and Cd showed high enrichment factor showing build up in the environment (Baruah and Khare 2010).

Impact of AMD in the streams and groundwater at the vicinity of collieries is a growing problem in northeast India. The Meghalaya State Pollution Control Board, Shillong (MSPCB 2007) reported a case of massive fish death in Lukha River on the eastern border of Jaintia Hills district, which was attributed to AMD contaminating the stream water and sediments. Swer and Singh (2003, 2004) have reported the lack of commonly found aquatic life forms such as fish, frogs and benthic macroinvertibrate such as Plecoptera, Ephemeroptera and Tricoptera in water bodies of coal mining areas in Jaintia Hills, Meghalaya. Overall, socio-economic and ecological impacts in the area includes: severe scarcity of freshwater resources for domestic use and drinking purposes by the local community causing breach of basic human right; lack of aquatic life in many rivers and streams and reduced vegetation diversity; decreased agricultural productivity etc. (Swer and Singh 2004). Swer and Singh (2004) further reported that water quality in the Jaintia Hills of Meghalaya is highly affected as evidenced by low pH (in the range of

Table 3 Concentration of some toxic elements present in northeast India and other Indian coals/lignite (mg/kg)

Parameters	As	Cu	Mn	Zn	Ni	Pb	Cr	Cd	References
Jaintia coalfield (Meghalaya, India)	1–3	2.8–40	36.6–81.5	8.5–36.6	2–9.8	2.4–13.7	17.9–55.5	5	Baruah and Khare (2010)
Makum coalfield (Assam, India)	0.04–0.24	9.86–30.35	15.27–63.81	–	–	5.06–24.13	–	–	Mukherjee and Srivastava (2005)
Jammu and Kashmir, India	9.5	16.7	39	17.3	42.5	13.5	31.5	1.8	Banerjee et al. (2000)
Damodar Koel Valley coal	8.2	21.4	57.7	33.3	28	17.9	47.5	2.2	Banerjee et al. (2000)
Wardha Godavari Valley coal	2.1	29.5	58.6	29.2	25	4.5	54.5	2.8	Banerjee et al. (2000)
Pench Kanhan Tawa Valley coal	5.8	24.3	85	26	22.7	10.2	33.7	2.1	Banerjee et al. (2000)

3–5), high conductivity, high concentration of sulphates, iron and other toxic metals, low dissolved oxygen (DO) and high biological oxygen demand (BOD). Such low pH, low DO, higher sulphate content and turbidity in water of coal mining areas are affecting the aquatic life.

Singh and Sinha (1992) reported variation of pH in northeastern coalfields, pH 2.8–4.1 in Churcha, pH 4.2–5.0 in West Chirimir, pH 5.2–5.6, pH 5.3–6.0 in Rakhikhol and pH 4.0–4.6 in Gorbi coalfields. Highly acidic mine water with high sulphate (up to 1500 mg/L) and Fe (40 mg/L) were reported in Margherita group of mines in Assam (Rawat and Singh 1982). Bhole (1994) reported pH of 3.9, 3.10 and 4.3 in Ledo, Tirap and Bargolia mines of Assam. Based on a similar study carried out in Makum coalfields in Assam by Equeenuddin et al. (2010), it was found that the mine discharges were highly acidic (up to pH 2.3) to alkaline (up to pH 7.6) in nature with high concentration of SO_4^{2-} and mine water was highly enriched with Fe, Al, Mn, Ni, Pb and Cd. In addition, ground water close to the collieries and AMD affected creeks were highly contaminated by Mn, Fe and Pb but major rivers were not much impacted by AMD due to their large volume of water. Different physico-chemical parameters of surface and groundwater near coalfields in northeast and other parts of India are shown in Table 4. As can be seen in Table 4, pH of surface water near Jaintia coalfield, Meghalaya, India is highly acidic as compared to surface water in other sites in India. The maximum concentrations of metals detected in groundwater near Makum coalfield, Assam, India was (mg/L): 0.018 for Cr, 0.2 for Ni, 0.108 for Zn, 2.18 for Mn, 3.9 for Fe, 1.1 for Al, 0.061 for Pb, and 0.009 for Cu, in river water, the maximum concentrations were (mg/L): 0.06 for Ni, 0.016 for Zn, 0.94 for Mn, 2.47 for Fe, 0.42 for Al, 0.017 for Cd, 0.056 for Pb and 0.021 for Cu (Equeenuddin et al. 2010). In a study by Abhishek et al. (2006), water quality parameters in groundwater in Jharia coalfield ranged: pH (6.72–7.94), TDS (213–530 mg/L), SO_4^{2-} (8.8–41.2 mg/L), Cl^- (19.8–96 mg/L), NO_3^- (3–77.7 mg/L), Fe (0.13–2.18 mg/L), Zn (0.02–0.04 mg/L), Pb (0.01–0.04 mg/L). The maximum TDS, NO_3^- and Fe concentrations exceeded the Bureau of Indian Standards (BIS) limit for drinking water quality. In surface water, water quality parameters varied between (Abhishek et al. 2006): pH (7.15–7.76), EC (250.6–470.6 μS/cm), TDS (237–616 mg/L), DO (2.5–5.8 mg/L), BOD (3.8–13.7 mg/L), Pb (0.01–0.03 mg/L), Zn (0.03–0.09 mg/L) and Fe (0.15–1.91).

Metals concentrations in stream sediments around Makum coal field of Assam ranged (mg/kg): 5.5–71.7, 100–386, 3.1–21.1, 0.48–2.1, 23.1–231, 101–9163 and 17.8–264 for Cu, Cr, Pb, Cd, Zn, Mn and Ni, respectively (Equeenuddin et al. 2013). The study further indicated that higher concentrations of all metals were available in exchangeable fraction under strongly acidic environment. Based on their mobility and potential bioavailability, metals were in the order of Cd $>$ Pb $>$ Mn $>$ Ni $\geq$ Zn $>$ Cu $>$ Cr.

4 Management and treatment strategies to reduce environmental impacts of coals

Since coal mining and its utilization in coal based industries is associated with environmental issues, it is necessary to manage or mitigate its impact on environment or clean coal prior to its utilization. An attempt was made by Dowarah et al. (2009) to achieve eco-restoration of a high-sulfur containing coal mine overburden dumping site through primary and secondary ecological succession of native plant species in Tirap Collieries, Assam, India. The study revealed that planting of herbaceous monocots with fibrous root systems such as citronella, lemon grass, *Saccharum spontaneum*, lianes and shrub species accelerates the ecological processes in an adverse mine overburden environment of Tirap colliery and a secondary sere ecological succession was observed in the restored mine site. In addition, 80 %–100 % vegetation coverage was observed, the plant species density was more than 80 %, and soil organic matter increased from 0.001 %–0.005 % to 0.5 %–1.3 %. Restoration refers to reinstatement of the pre-mining ecosystem in all its structural and functional aspects (Bradshaw 2000). Re-vegetation plays a crucial role in enhancing the soil fertility status in mine spoil and in the stabilization of dump slopes by creating mechanical reinforcement of dump material and enhancing shear strength of dump material (Singh 2011; Singh et al. 2012a, b). Soil structure development, nutrient cycling, and soil chemical and physical limitations to plant growth are mediated and mitigated by microorganisms and they play a very important role in eco-restoration (Singh and Singh 2006).

Mineral matter and sulfur exhibit harmful effects on utilization of coal. De-sulfurization and de-ashing are essential for sustainable utilization of low rank high sulfur coals used in different industries (Baruah et al. 2006; Baruah and Khare 2007b; Saikia et al. 2013). Sequential solvent extraction was found to be an effective method of desulfurization of high sulfur containing Assam coal, especially for organic sulfur, which could be removed up to 89 % (Das and Sharma 2001). Investigation on desulfurization of coal samples from Boragolai and Ledo collieries of Makum coal field, Assam, India using alkali treatment leads to over 70 % removal of inorganic sulfur, and removal of sulfur increased with increase in alkali concentration and treatment time (Mukherjee and Borthakur 2003). In another study, for the same coal, solvent extraction and alkali treatment showed successful removal of organic and inorganic sulfur. Solvent extraction using dimethyl formamide (DMF) increased desulfurization of the oxidized Baragolai and Ledo coals up to 95 % and 93 % for inorganic sulfur and 31 % and 23 % organic sulfur, respectively, while the alkali treatment showed complete removal of inorganic sulfur and a maximum of 33 % and 26.4 % organic sulfur for these coals, respectively (Baruah and Khare 2007b). Alkali treatment of high sulfur Assam coal using mixtures (1:1) of 16 % sodium hydroxide and potassium hydroxide solution followed by 10 % hydrochloric acid could remove 50 %–54 % of the ash, total inorganic sulfur, and around 25 % organic sulfur (Mukherjee 2003). 9.4 % of the total organic sulfur was removed by electron transfer process (Borah and Baruah 1999). In another study, approximately 93 % and 98 % of the pyritic sulfur was removed in the case of the Baragolai and Ledo coal of Makum, Assam, respectively, using 15 % (v/v) hydrogen peroxide + 0.1 N sulfuric acid (Mukherjee and Srivastava 2004). An attempt was made to clean some low rank medium to high sulfur coal samples from northeast India using low ultrasonic energy (20 kHz) in the presence of H_2O_2 solutions and it showed removal of 31 %, 48 %, 51 %, 48 % and 32 % of total sulfur, organic sulfur, pyritic, sulfate sulfur and ash, respectively (Saikia et al. 2014b). In a similar study, treatment using application of ultrasonic energy (20 kHz) in aqueous and mixed alkali media (1:1 KOH and NaOH) on coals collected from Assam and Nagaland, India showed that the maximum removal of ash, pyritic sulfur, sulphate sulfur and total sulfur were 87.52 %, 83.92 %, 12.50 % and 18.80 %, respectively (Saikia et al. 2014c). Ultrasound assisted coal de-sulfurization and de-ashing is partially green approach that has been recently studied by other researchers (Hoffmann et al. 1996; Ze et al. 2007; Wang and Yang, 2007; Mello et al. 2009; Shen et al. 2012).

In addition to several physico-chemical desulfurization methods, biodesulfurization using *Thiobacillus ferrooxidans* (ATCC 13984) was attempted for Assam coal (Dastidar et al. 2000). Results showed that the rate of pyritic sulfur removal was retarded at higher concentrations of ferrous and ferric ions that need to be controlled to maintain high rate of removal (Dastidar et al. 2000). In general, AMD can be remediated by two generic approaches i.e. active or passive treatment (Skousen et al. 1998; Wolkersdorfer 2008). Active treatment requires the use of alkaline materials (lime, limestone, hydrated lime, caustic soda, soda ash, etc.) or aeration to reduce acidity and precipitate metals, while passive (abiotic and biological) treatment allows chemical and biological processes to take place naturally in a controlled environment (Costello 2003; Johnson and Hallberg 2005; Sheoran and Sheoran 2006; Rios et al. 2008; Sheoran et al. 2010). A pilot plant

Table 4 Physico-chemical characteristics of surface water around coalmines in northeast and other parts of India (in mg/L except pH)

Item	Parameter	pH	TDS	Ca	Mg	Fe (μg/L)	Cu (μg/L)	Mn (μg/L)	Zn	Ni	Pb	Cr	Cd	References
Surface water	Jaintia coalfield (Meghalaya, India)	2.6–5.6	174–2078	0.33–108.2	0.72–26.27	1.5–66.1	bdl-0.09	0.01–3.25	0.011–2.05		bdl-0.46	bdl-0.05	bdl-0.06	Sahoo et al. (2012)
	Jharia coalfield(Jharkhand, India)	6.83–9.71	5–885	6.9–100.1	3.8–136.9	0.01–0.82		0.01–3.29						Sarkar et al. (2007)
	Singrauli, Madhya Pradesh	7.6–8.6	315–1425	17.6–38.5	1.95–12.7	0.072–2.27	0.004–0.013	0.005–0.153	0.015–0.058	0.012–.034		bdl-0.200		Khan et al. (2013)
	Makum (Assam, India)	6.1–7.4		6.2–31.4	2.5–16.5	0.41–2.47	bdl-0.021	0–0.94	bdl-0.016	bdl-0.06	0.008–0.056		bdl-0.017	Equeenuddin et al. (2010)
Groundwater	Jaintia coalfield (Meghalaya, India)	4.8–6.8	93–234	2.6–23.5	2.2–11.7	0.024–2.3	bdl-0.01		bdl-0.06		bdl-0.03	bdl-0.01		Sahoo et al. (2012)
	Jharia coalfield (Jharkhand, India)	4.6–7.68	5–320	16.4–175.6	4.4–174.5	0.001–11.94	0.002–0.21		0.01–3.95					Sarkar et al. (2007)
	Jharia coalfield (Jharkhand, India)					0.693	0.0282	0.74	0.153	0.0223	0.0125			Chandra and Jain (2013)
	Singrauli coal field (Madhya Pradesh, India)	7.83–8.7	176–1845	9.62–41.68	bdl-26.3	bdl-1.45	0.003–0.068	0.002–0.222	0.014–0.797	0.009–0.03		0.004–0.266		Khan et al. (2013)
	Makum (Assam, India)	4.2–7.8		4.8–27.52	2.3–12.5	0.15–3.76	bdl-0.009	0.01–2.18	bdl-0.108	bdl-0.2	0.0–0.061	bdl-0.018		Equeenuddin et al. (2010)

Table 5 Pollution standards for air quality in India

Pollutant	Time-weighted averages	Concentration in ambient air (mg/L)		
		New coal mines (after December 1998)	Existing coalfields/ mines	Old coal mines (Jharia, Raniganj, Bokaro)
SPM	Annual average	360	430	500
	24 h	500	600	700
RPM	Annual average	180	215	250
	24 h	250	300	300
SO_2	Annual average	80	80	80
	24 h	120	120	120
NO_x	Annual average	80	80	80
	24 h	120	120	120

consisting of sequential alkalinity producing (SAP) system coupled with biological processes was designed for treatment of AMD from coalmines of Meghalaya, northeast India (Baruah et al. 2010). The treatment system was found to be effective in reducing TDS, conductivity, sulphate and toxic elements.

In India, the Ministry of Environment and Forests (MoEF) plays a key role in regulating the environmental impacts of mining and in providing clearances for mining in forest lands. Some environmental protection measures include: prevention of pollution at source; ensuring polluters pay principle; protection of heavily polluted areas and river stretches; encouragement of development and application of best available technological solutions; and involving the public in decision making (Mehta 2002). Under Mineral Concession Rules, 1960, it is required to specify the area indicating impact of mining activity on forest, land and environment, scheme for restoration of the area by afforestation, adoption of pollution control devices. According to Article 23 of the Mineral Conservation and Development Rules (1988), conditions for the abandonment of any mine need to be laid down by the mining company and provision of a plan for dealing with the environment, and is liable to protect and control pollution during the mining and post mining operations. The law further lays guidelines to restore or protect the flora of the area under the mining lease and nearby areas, technically, economically and environmentally.

The main environmental acts that impact the mining industry in India are: The Wildlife (Protection) Act, 1972 (amended in 1991); The Water (Prevention and Control of Pollution) Act, 1974 (amended in 1988); The Forest (Conservation) Act, 1980 (amended in 1988); The Air (Prevention and Control of Pollution) Act, 1981 (amended in 1988); and The Environment (Protection) Act, 1986 (with rules 1986 and 1987). Separate pollution standards for air quality and coal mine effluents has been laid down by Central Pollution Control Boards for coal mining in India (Tables 5, 6).

Table 6 Pollution standards for coal mine effluents

Parameter	Level
pH	5.5–9.0
TSS (mg/L)	100
Oil and grease (mg/L)	10
COD (mg/L)	250
BOD (mg/L)	30
Phenolics (mg/L)	1.0

In order to achieve sustainable utilization of coal resources integrated approach considering various aspects to reduce its environmental impacts is necessary. Proper implementation of regulatory rules and policies is as important as other management strategies to deal with environmental issues.

5 Conclusions

Demand for coal in India is projected to increase dramatically in short to medium term. This would result in increased coal mining in different parts of India including northeast region. Since, coals in northeast India is characterised by high sulfur and volatile matter contents that exhibits more potential harmful impacts, extra efforts are required to manage these coals to reduce its environmental impacts in the region. More studies need to be done in the field to assess the impact of coal mining on biodiversity, soil, air, surface and ground water in northeast India. Although several researches on desulfurization, de-ashing and demineralization techniques have been made, effort should be made to do further research on developing effective, low cost and environmental friendly technologies to clean coal and to use these techniques in the field. Further, it is essential to encourage and emphasize on alternative clean sources of energy to meet future energy demands.

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