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Final Technical Report

of R&D Scheme entitled

Impact of Mining on Water Resources in Jaintia Hills, Meghalaya

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Submitted

by

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to

R&D Division

Central Water Commission

Ministry of Water Resources, Government of India, New Delhi

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1. Introduction

1.1 Meghalaya

Meghalaya is one of the eight states situated in North-Eastern Region of India and often acknowledged as 'The Abode of Clouds'. Its coordinates lie between 25^{0}02'E - 26^{0}07'N latitude and 89^{0}49'E and 92^{0}50' E longitude. The total geographical area of the state is 22,429 sq. km. The landscape comprises of undulating topography interspersed with low and high hills, deep gorges and valleys. The boundary of Meghalaya is shared by Assam from three sides the north, west and east. The southern side forms the international boundary with Bangladesh. The state can, broadly, be divided into three physiographic zones (i) the Central Plateau Region between 900-2000 m (ii) Sub-montane region in continuation with the Central Plateau below 900 m which gradually merges with the plains in the West and North and (iii) Border region which stretches south-wards abruptly from the Central Plateau to the plains in Bangladesh.

The climate of the state is directly controlled by the southwest monsoon originating from the Bay of Bengal and the Arabian Sea. The climate of Meghalaya is generally very humid. It is directly influenced by the south west monsoon and the north east winter winds. The four main seasons of Meghalaya are Spring (March to April), Monsoon (May to September), Autumn (October to November) and Winter (December to February). The rainfall is heaviest in south eastern Garo hills and decreases in the central regions and in the north. Cherrapunjee-Mawsynram region receives the heaviest rainfall with an annual average of 12670 mm. The average rainfall in some areas of the state is 12000 mm. The temperature starts warming up with the advent of spring and reaches the maximum in the summer (monsoon) months of May and June. The winter is quite severe with minimum temperature coming down to as low as 2°C in the Khasi Hills. April and May are the warmest months and January is the coldest month. The climatic conditions vary substantially from place to place due to wide differences in altitude. Most of the precipitation in the state occurs between April and October.

About 70% (17,146 sq. km.) of the geographical area is covered with forest. The forests of Meghalaya are rich and diverse comprising broadly of tropical evergreen, tropical semi-evergreen, tropical moist deciduous, sub-tropical moist broad leaves, sub-tropical pine forest, temperate forest type, grass land and savannah forest types[1]. Meghalaya forests support a vast floral diversity, including a large variety of parasites, epiphytes, succulent plants and shrubs. Commercially important tree species found in the region are Sal, Pine, Teak, Birch, Titachap, Walnut, Mahagony, Schim, Beach, Nahar, Agar, Champs, Gamari and others. Meghalaya is also the home to a large variety of fruits, vegetables, spices, and medicinal plants. Meghalaya has a substantial number of interesting fauna comprising of a large variety of mammals, birds, reptiles and insects etc. The important mammal species include elephants, bear, red pandas, civets, mongooses, weasels, rodents, gaur, wild buffalo, bats, deer, wild boar and a number of primates. Forests of Meghalaya are a natural habitat of rare animal species, the Hoolock Gibbon, which is a sole ape species in India and is found in the forests of many north-eastern areas, including Meghalaya.

A dense network of streams and rivers exist in Meghalaya. They flow either towards Brahmaputra River in the north or in the Surma valley of Bangladesh in the south. Soils of Meghalaya are slightly acidic in nature, rich in organic carbon with low content of phosphorus and with available potassium ranging between low to medium. The texture of soils varies from loamy to fine loamy. The soils of the alluvial plains adjacent to the northwest and southern plateau are very deep, dark brown to reddish-brown in colour and sandy-loam to silty-clay in texture.

The State is comprised of three Hill regions namely, Khasi Hills, Jaintia Hills and Garo Hills. The state has eleven districts viz. 5 in Garo Hills, 4 in Khasi Hills and 2 in Jaintia Hills. According to 2011 Census, the total population of the state is 29,64,007. The populations residing in rural and urban areas are 79.93% and 20.07%, respectively. The tribal inhabitants are predominantly the Khasi (Khasi, Pnar, Bhoi and War) and Garo communities which constitute about 86.15% of State's total population. The district map of Meghalaya is presented in Figure 1.1.

Figure 1.1: Location map of the State of Meghalaya and its various districts

(Source: WWW. http://mssat.nic.in/districts.htm)

Meghalaya has predominantly an agrarian economy as agriculture is the main occupation of about 80% of people of the state. Rice (*Oryza sativa* Linn.) and maize (*Zea mays* Linn.) are the major food crops. Important fruits grown are orange (*Citrus reticulate* Blanco), pineapple (*Ananas comosus* Merrill), lemon (*Citrus limon* Burm. f.), guava (*Psidium guajava* Linn.), jack fruit (*Artocarpus heterophyllus* Lam.) and bananas (*Musa* sp.). Potato (*Solanum tuberosum* Linn.*)*, jute (*Hibiscus cannabinus* Linn.), cotton (*Gossypium* sp.), arecanut (*Areca catechu* Linn.), ginger (*Zingiber officinale* Rosc.), turmeric (*Curcuma domestica* Valeton), betel leaf (*Piper betle* Linn.) and black pepper (*Piper nigrum* Linn.) are the chief commercial crops. In addition to agriculture and horticulture, people of rural areas are also dependent on mining and mining related activities, fishing, hunting, collection of NTFPs, firewood and charcoal business for their livelihood and income generation.

1.1.1 Geology

Geologically the Meghalaya plateau comprises of rocks from the oldest Precambrian gneissic complex to the recent alluvium formations. The stratigraphic sequence is comprised of 1. Cretaceous-Tertiary sediments; 2. The Sylhet trap; 3. Lower Gondwana rocks; 4. Shillong Group of rocks; and 5. Precambrian gneissic complex (Basement gneiss).

The Precambrian gneissic complex of para-orthogneisses, migmatites and the Shillong Group of rocks comprising mainly quartzytes are exposed in the central, eastern and northern parts of the Meghalaya plateau. They are intruded by basic and ultrabasic intrusives and late tectonic granite plutons. The lower Gondwana rocks of Permo-carboniferous age are recognized at the western part of Garo Hills and consist of pebble bed, sandstone, and carbonaceous shale. The Sylhet trap of middle Jurassic age comprising mainly of basalt, rhyolites, acid tuffs, is exposed in a narrow E-W strip along the southern border of Khasi Hills. The Cretaceous- Tertiary sediments occupying southern part of the Meghalaya plateau comprise of the Khasi Group (arenaceous facies), the Jaintia Group (calcareous facies) and the youngest formation the Garo Group which is represented as Simsang, Bagmara and Chengapara formations. Besides these the Dupi Tilla group of mid-Pliocene age occurs in the western part of Garo Hills and towards south of Khasi Hills. Isolated patches of older Alluvium overlie the Tertiary rocks along the southern and western borders of the State. The recent Alluvium formation is mostly found in the river valleys of Garo and Khasi Hills areas. The geological map of the State is shown in Figure 1.2.

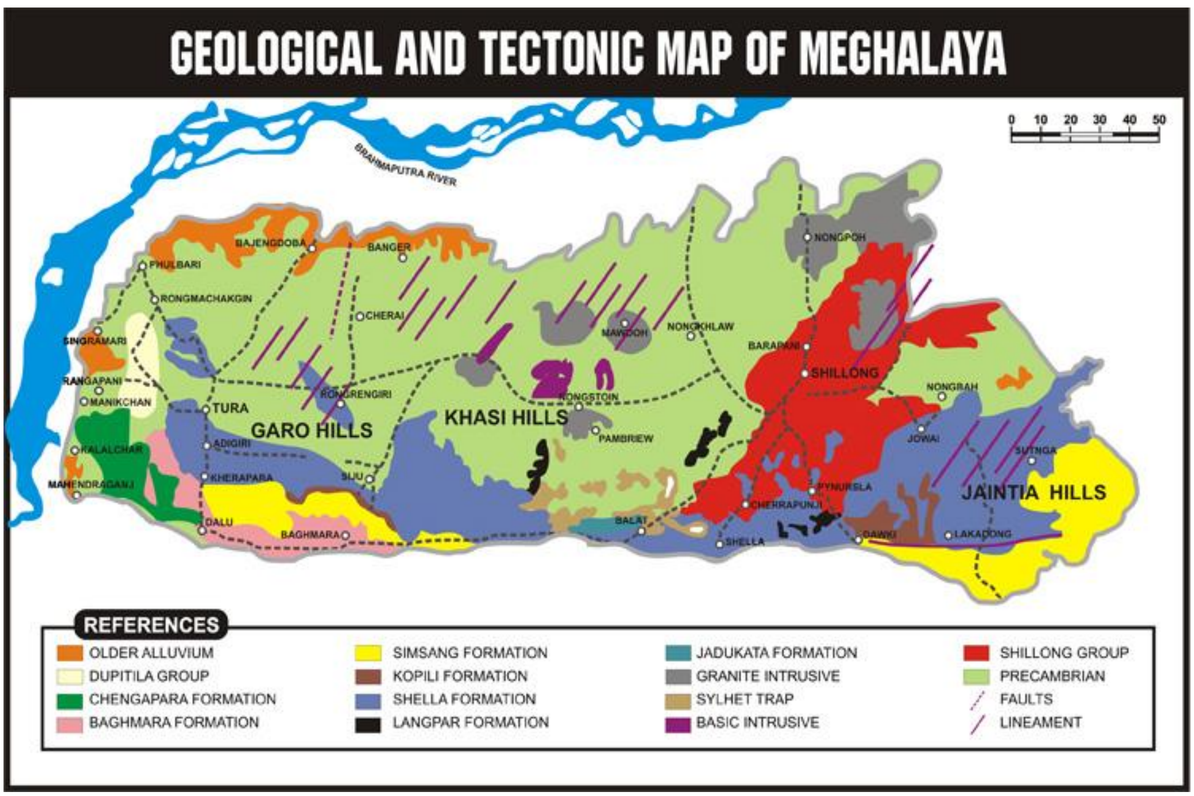

Figure 1.2: Geological map of Meghalaya (Source: http://megdmg.gov.in/features.html)[2]

1.1.2 Minerals and Mining

The State of Meghalaya is endowed with deposits of a number of minerals such as coal, limestone, kaolin, clay, granite, iron ore, glass-sand, quartz, feldspar, sillimanite, bauxite, rock phosphate, gypsum and uranium. Coal and limestone occur in all three hill regions of

Meghalaya, predominantly near the southern fringe of the state. Substantial amount of uranium of good quality has been discovered in West Khasi Hills. Other minerals such as apatite occur in Jaintia Hills; china clay in East and West Garo Hills, Jaintia Hills and East Khasi Hills; copper, lead-zinc, silver and titanium minerals in East Khasi Hills district; feldspar and rock phosphate in East Garo Hills and Jaintia Hills; fireclay in East Khasi Hills and West Garo Hills; granite in West Khasi Hills; iron ore (magnetite) in East Garo Hills; quartz and silica sand in East Garo Hills, West Garo Hills and East Khasi Hills; and sillimanite and uranium in West Khasi Hills. These minerals are utilized in several mineral-based industries in the country. Limestone is exported to Bangladesh and also used in the state for manufacturing of cement. Earlier the State exported coal also to Bangladesh earning foreign exchange for country. However, coal export officially was halted after the imposition of ban of coal mining in Meghalaya by the Honourable National Green Tribunal of India.

The minerals that have been extensively exploited in the state of Meghalaya are Coal and Limestone. Besides, Clay, Sillimanite and some other minerals have also been utilized. Coal is found in all three hill regions of Meghalaya viz. Jaintia Hills, Khasi Hills and Garo Hills. Although maximum deposit of coal is found in Garo Hills but maximum mining have taken place in Jaintia Hills due to its relatively gentle topography and easy accessibility. The production of coal has been done by private mines owners in the un-organized sector due to unique land tenure system in the state. Some of the prominent coal mining areas in the state include West Dadenggiri, Siju, Balpakram, Pyndengrei, Langrin, Mawlong-Shella, Laitryngew and Bapung. About 9% of the country's total limestone reserves are distributed in the state of Meghalaya. Mining is carried out by open cast method of mining. Both large scale and small scale mining of limestone are taking place in Meghalaya. It is done by cement manufacturing companies as well as by individuals and communities. Jaintia and Khasi Hills are the areas where limestone deposits have been used for manufacturing of cement and production of quick lime and other products. The distribution of other minerals such as clay, kaoline, sillimanite etc. is in localized areas and mining of these minerals has not yet attracted so much attention by the people.

Minerals in Meghalaya are distributed all through the State however the southern part is relatively richer in coal and limestone. The distribution of various minerals in the state of Meghalaya as mapped by Department of Mining and Geology, Government of Meghalaya is shown in Figure 1.3.

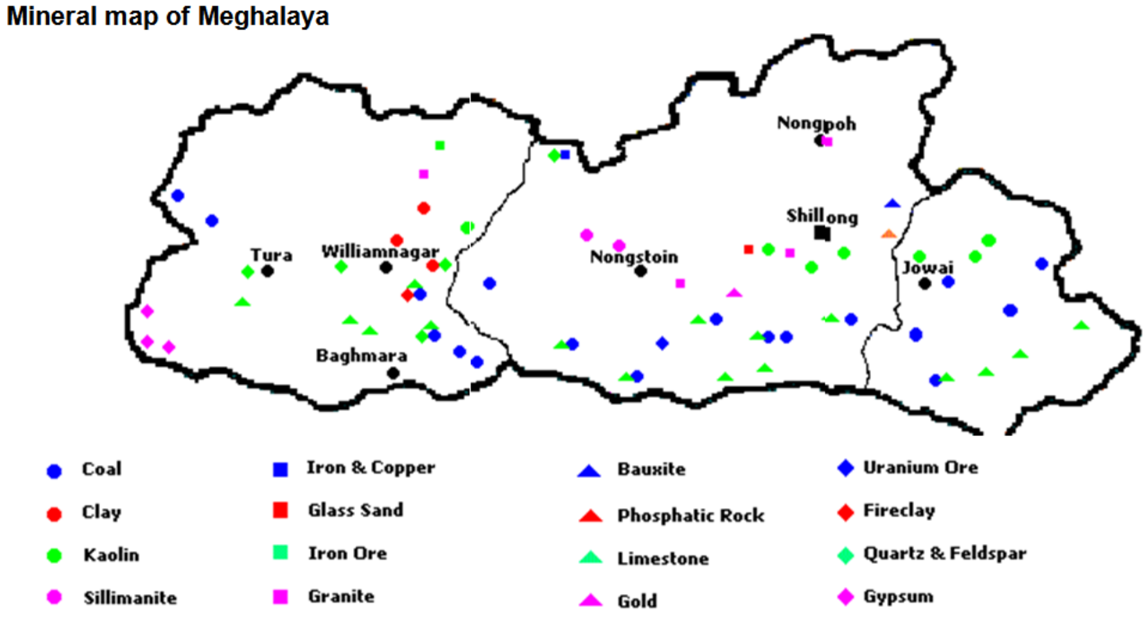

Figure 1.3: Mineral Map of Meghalaya (Source: http://megdmg.gov.in/features.html)

1.1.3 Environmental Impacts of Mining in Meghalaya

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. In Meghalaya, although different minerals are mined, the impact of mining has been studied in respect to coal and limestone mining. It is reported that mining operation, undoubtedly has brought wealth and employment opportunity in the State, but simultaneously has led to extensive environmental degradation and erosion of traditional values in the society. Environmental problems associated with mining have been felt severely because of the region's fragile ecosystems and richness of biological and cultural diversity.

The indiscriminate and unscientific mining and absence of post mining treatment and management of mined areas are making the fragile ecosystems more vulnerable to environmental degradation and leading to large scale land cover/land use changes. The land degradation and water pollution due to mining have affected the traditional agriculture, horticulture, availability of bio-resources etc. in the mining areas of Meghalaya. The primitive and unscientific 'rat-hole' method of coal mining adopted by private operators and related activities have caused environmental degradation and ecosystem destruction in all three Hills regions of the state. However, severe impact can be seen in Jaintia Hills where maximum coal production takes place in the state.

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 Meghalaya [3]. Coal mining has adversely affected the vegetation and the density of trees, shrubs and herbs in mined areas. Studies revealed that loss of forest cover, pollution of water, soil and air, depletion of natural flora and fauna, reduction in biodiversity, erosion of soil, instability of soil and rock masses, changes in landscape and degradation of agriculture land are some of the conspicuous environmental implications of limestone mining [4,5,6,7]. The mining of other minerals is taking place at very small scale and therefore their impacts have been found localized in small areas. However impact of mining of these minerals is yet to be studied.

1.2 Jaintia Hills Region of Meghalaya

1.2.1 General Information

The Jaintia Hills region includes two easternmost districts namely East Jaintia Hills and West Jaintia Hills) of Meghalaya and covers a total geographical area of 3819 sq. km. It occupies 17.03% of the total area of the State. The Jaintia Hills lies between North latitude 240 58' and 260 03' and East longitude 910 59' and 920 51'and covers about 17 percent of the total area of Meghalaya. The population is 2,99,108 as per 2001 census. The area is hilly and bounded by Karbi Anglong district (Assam) in north, North Cachar Hills district (Assam) in east, East Khasi Hills district (Meghalaya) in the west and Cachar Hills district (Assam) and Bangladesh in the south. The area is composed of undulating to hilly landscapes dissected by numerous rivers and streams. On the northern and western borders, these hills take the form of tumbled ranges, which run for the most part north and south and have a general height of two to three thousand feet.

The climate of Jaintia Hills shows a variation from the warm, humid tropical in the plains in the eastern and southern parts and temperate climate is experienced in the western part around the Jowai town. The climatic conditions vary substantially from place to place due to wide differences in altitude. Therefore, according to the prevailing weather condition over the years, the district can be grouped into four conspicuous seasons namely winter season, pre-monsoon season, monsoon season and retreating season. Location of Jaintia Hills region is shown in Figure 1.4.

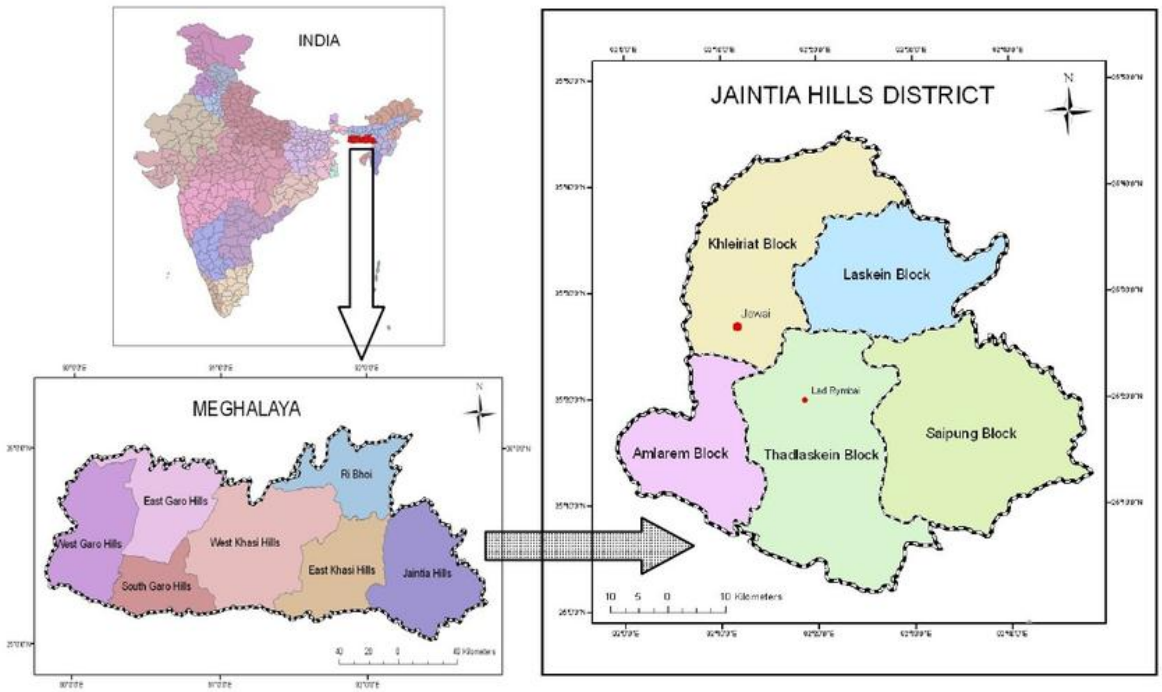

Figure 1.4: Location map of Jaintia Hills region, Meghalaya

The Jaintia Hills region is rich in natural resources. The heavy and long monsoon supports luxuriant forest of pine over the plateau and deciduous forest along its fringe areas against the plains. Jaintia Hills is also rich in wildlife represented by elephants, tigers, bears, wild boars, leopards, golden cats, leopard cats and jungle cats, deer of various kinds, monkeys of different types. There are also many rare and interesting birds including the hornbills, partridges, pheasants, teals, snipers, geese, ducks and quails. The water bodies harbour many species of fishes, amphibians and numerous invertebrates. The satellite imagery showing Jaintia Hills region presented in Figure 1.5.

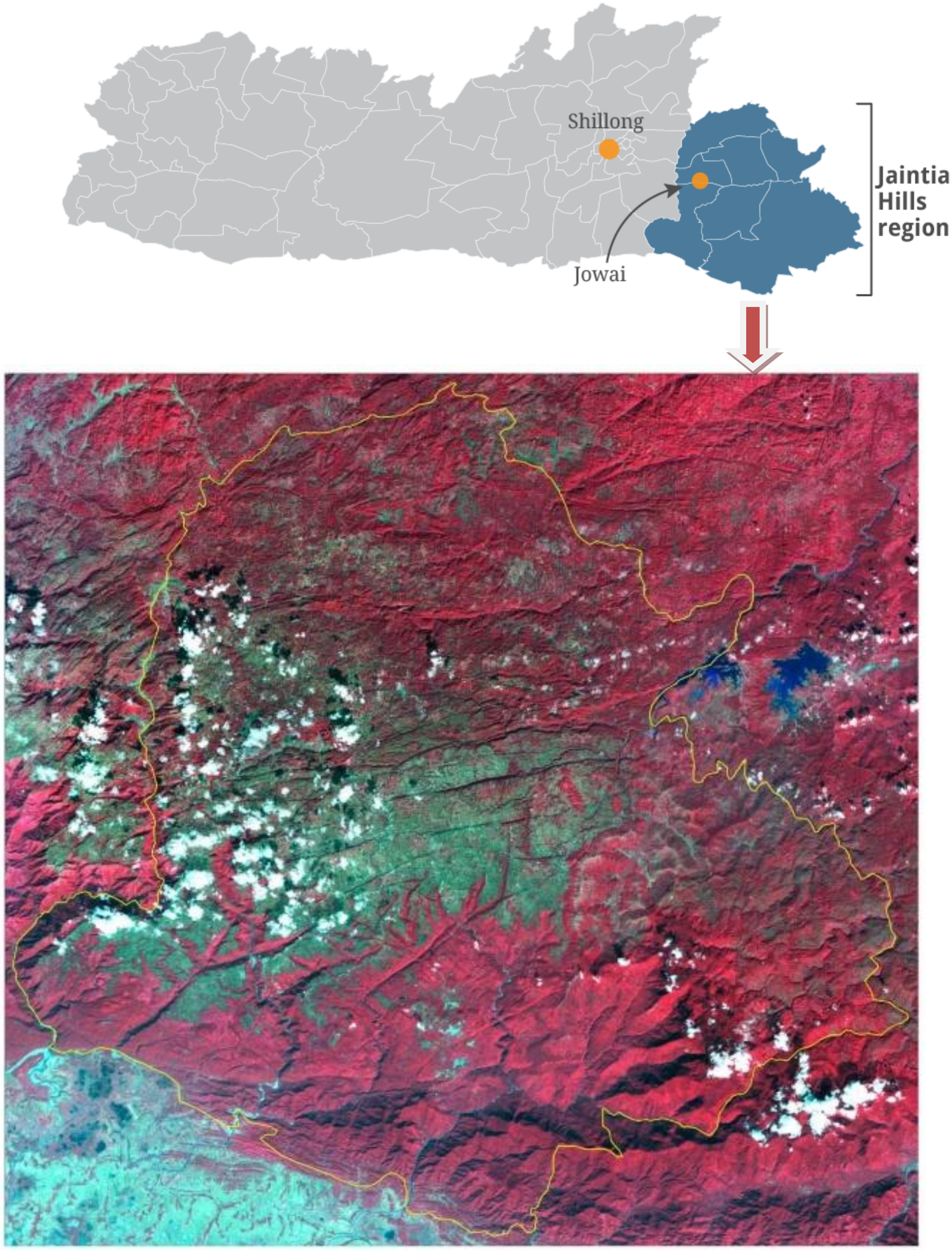

Figure 1.5: Map showing Jaintia Hills Region and Satellite Imagery of the area[8]

(Source: North Eastern Space Applications Centre, Umiam, Meghalaya)

1.2.2 Geological Setting of Jaintia Hills

The Jaintia Hills region falls mainly within the Shillong or Meghalaya Plateau which is constituted mainly of Precambrian rocks of gneissic composition in which granites, schists, amphibolits, calc-silicate rocks occur as inclusions of various dimensions. The gneisses form the Basement Complex for the overlying Shillong Group of rocks which is separated by an unconformity indicated at places by the occurrence of a conglomerate bed. The presence of primary structures like current bedding, ripple marks etc. indicated that quartzites of the Shillong Group are of sedimentary derivative later metamorphosed to quartzites. These occur mostly as thick layers. Grainite Plutons occur as isolated patches in the region, intruding the Basement Gneissic complex and Shillong Group of rocks. The Granites occur as intrusive body in the Basement Gneissic complex. Both Porphyritic and fine-grained pink granite occur in the area. The Generalized geological succession of the Jaintia Hills region is depicted in Table 1.1.

Table 1.1: Generalized geological succession of the Jaintia Hills

Geological Age	Group	Formation	Rock Type
Quaternary			Undifferentiated fluvial sediments (occurring as valley fill deposits and in the southern plain)
Unconformity			
Eocene- Oligocene	Barail group	-------	Coarse sandstone, shale, minor coal lenses carbonaceous shale,
Unconformity			
Palaeo- Eocene	Jaintia Group	Shella (600m)	Alteration of sandstone and limestone.
Unconformity			
Neo-Proterozoic – Lower Palaeozoic		Granite Plutons	Porphyritic coarse granite, pegmatite, aplite/quartz vein etc.
Intrusive Contact			
Palaeo-Mesoproterozoic	Shillong Group	Upper Division	Mainly Quartzites intercalated with phyllites.
		Lower Division	Mainly schists with Calc Silicate rocks, carbonaceous phyllite and thin quartzite layers.
Unconformity (Shared conglomerate)			
Archaean(?)-Proterozoic (Undiff)	Basement Gneissic Complex		Mainly quartzo-feldspathic gneiss with enclaves of granites, amphibolites, schists etc.

The Shella Formation of Jaintia Group consists of alteration of sandstone and limestone occurs in the south-central and south-western part of the district. The shelf facies of Barail Group, consists of fairly coarse grained sandstone, shale, carbonaceous shale with streaks and minor seams of coal and occupy the south-eastern part of the region. The Quaternary fluvial sediments occur as valley-fill deposits and in the extreme southern plains bordering Bangladesh. The geological map of Jaintia Hills is presented in Figure 1.6.

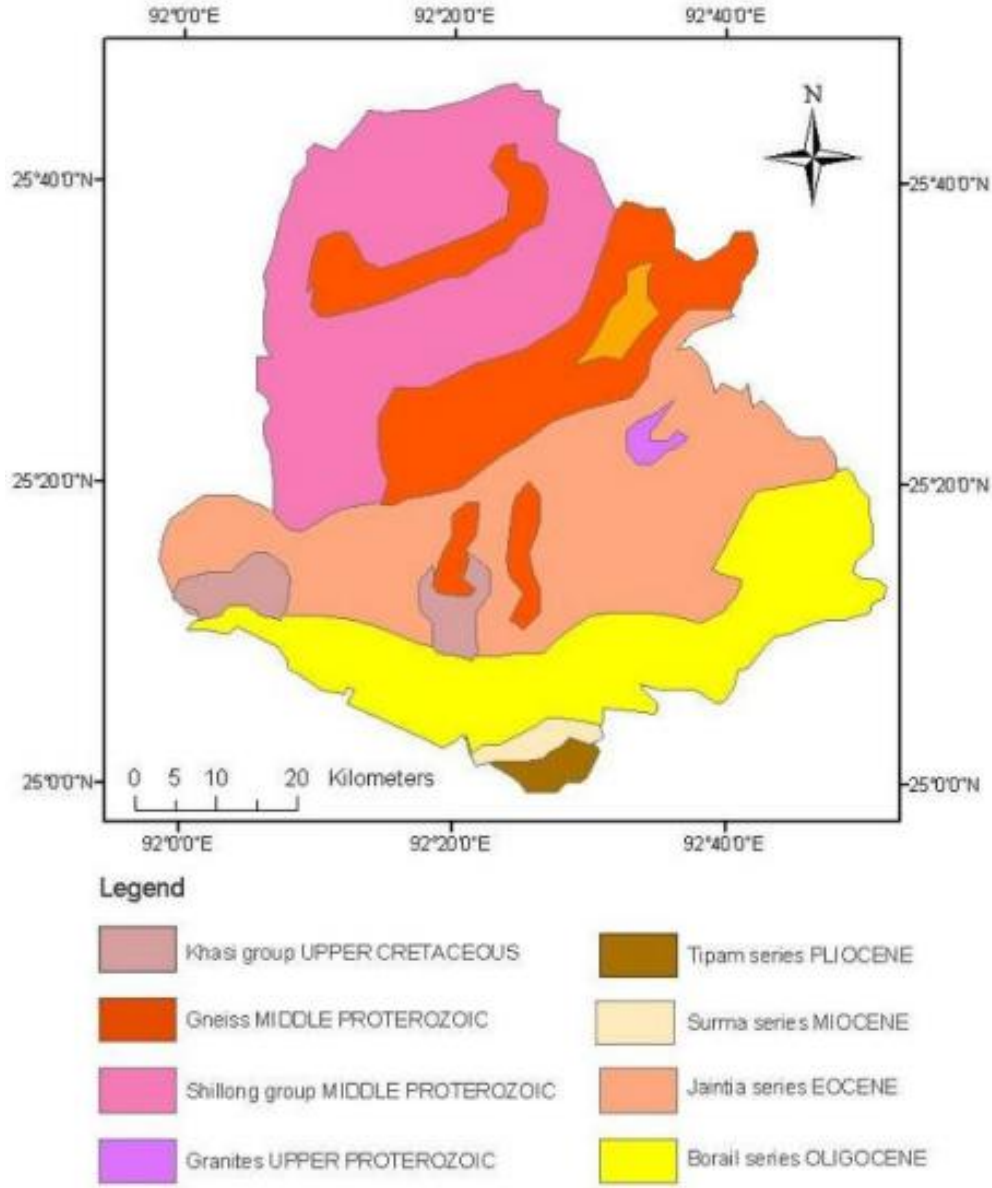

Figure 1.6: Geological map of Jaintia Hills Map (Source: GSI, 1974)

The Entisol, Inceptisol and Alfisol are the Soil group classifications present in Jaintia Hills region. Black soils (16082.4 ha), Red soils (264899.4 ha), Alluvial soils (16631.6 ha), Sandy soils (36522.6 ha), and Acid soils (381100 ha) have been reported in the region. Soil fertility status is generally low to medium. The soil is mostly sandy, reddish brown to yellow brown in co lour, acidic in reaction with low water holding capacity and has poor contents of organic matter and nutrients. The PH value ranges between 4.1 to 5.6 .The concentrations of organic carbon content varies from 0.28 to 3.1 percent. Low phosphorus content is the characteristics of the soil of the District varying between 1.8 and 4.5 Kg/ha. The Potassium content ranges between 28.0 and 112.0 Kg/ha, which is quite lower than normal soil. Distribution of different types of soil found in Jaintia Hills region of Meghalaya is depicted in map shown in Figure 1.7.

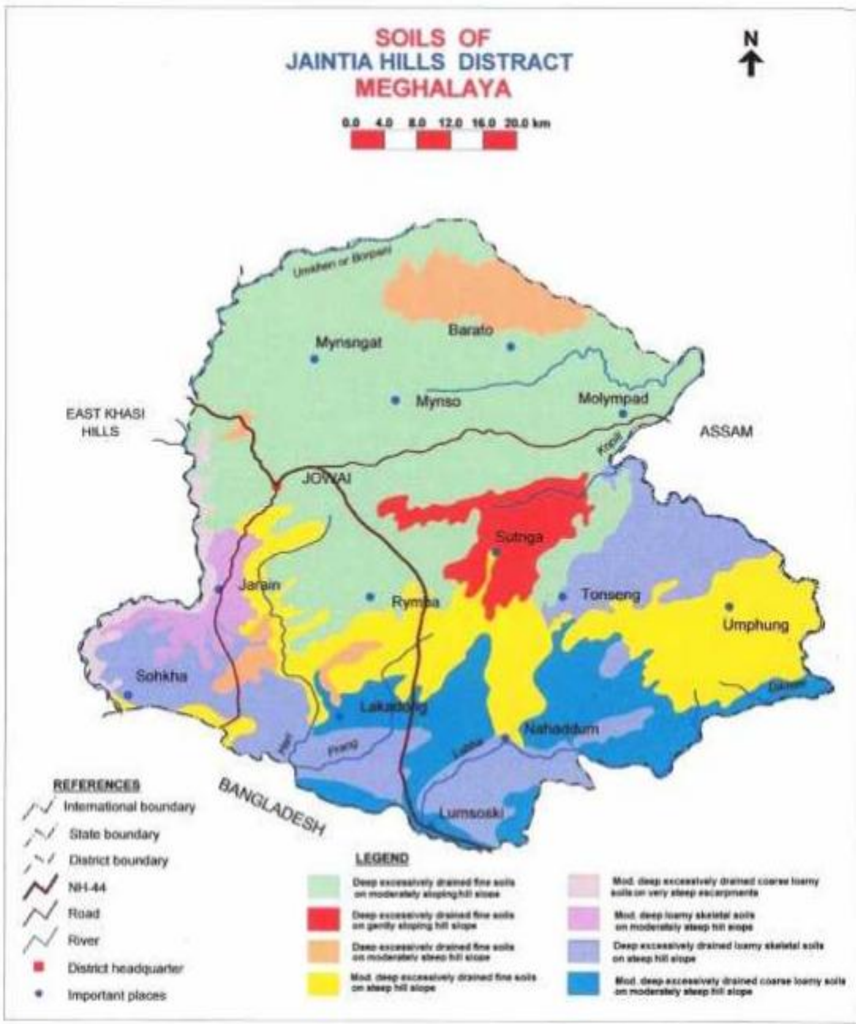

Figure 1.7: Map showing different types soils found in Jaintia Hills

(Source: http://agricoop.nic.in**)**

1.3 Information Gap

In general, we know that mining in Meghalaya has influenced the people of the State both in positive and negative ways. The positive influences include employment and income generation to the mine owners, miners, transporters, businesses linked to mining activity. The negative effects of mining include environmental degradation, depletion of natural resources, loss of livelihood of people traditionally dependent on various activities other than mining, increasing economic disparity and social problems.

The information on effects of mining on water resources is limited and scattered, and thus needed to be investigated. Such information is essential to strengthen the water resource management practices and sustainable development of the area..Under this project studies were undertaken to analyze the impact of mining on water resources in Jaintia Hills, Meghalaya. The results of the studies are compiled in this report. Based on information generated and gathered in the present study measures have been suggested to mitigate the adverse impacts of mining activity on water resources, in particular and the environmental, in general.

1.4 Structure of the Report

The information generated by our own field and laboratory analysis and collected from secondary sources during the course of present study has been compiled in this report in five chapters, namely 1. Introduction; 2. Minerals in Meghalaya; 3. Mining in Jaintia Hills; 4. Water Resources in Jaintia Hills; & 5. Impact of Mining on Water Resources. The report is supported by relevant figures and data. Salient points of each major topic/section are listed in Boxes included at the end of the section. The data/information taken from studies of other researchers, publications etc. are duly referred and references are given at the end of the report.

2. Minerals found in Meghalaya: A Brief Account

The major minerals of Meghalaya are Coal, Limestone, Clay, Uranium and Sillimanite. These minerals are utilised in several mineral-based industries in the country. The mined coal and limestone are exported to Bangladesh as well. Coal and limestone are the only major minerals mined in the State even though with the presence of many other minerals. A brief account of the various mineral resources present in Meghalaya is given below:

2.1 Coal

One of the main mineral resources found in Meghalaya is coal. The total coal reserves found in Meghalaya is estimated about 576.48 million tones. The coal found in Meghalaya belongs to tertiary age and is generally of sub-bituminous type. The coal seams varying from 30 to 212 cm in thickness occur imbedded in sedimentary rocks, sandstones and shale of the Eocene age [2].

2.1.1 Occurrence of Coal

Garo Hills has the highest reserve of coal deposits followed by West Khasi Hills, Jaintia Hills and East Khasi Hills. However, in terms of coal production, maximum extraction has taken place from Jaintia Hills due to gentle topography and facilities developed for transport and marketing.

In Khasi Hills coal deposits are found in Bairung, Sohra, Laitryngew, Mawlong-Shella, Mawstoh, Mawsynram, Mawdon, Mao-nai-chhora, Mawbehlarkar, Lyngkyrdem and,Pynursla.

The prominent coalfields of Jaintia Hills District are Bapung, Lakadong, Sutnga, Rymbai, Chiehruphi, Lumshnong, Narwan, Byrwai, Sohkymphor, Myntriang, Jalyiah, Lumchyrmit, Lumskhen, Rangad, Iapmala, Musniang, Moollamanoh, Moolang, Mookhain, Semmasi, Umkyrpong, Lakasein, Mooriap, Jalaphet, Moolait, Lamyrsiang, Mynthning, Kyrluh, Sakhain, Umthei, Umlawang, Tluh, Moolamylliang, Latyrke, Nongkhlieh elaka, Khliehriat, Lad Rymbai, Byndihati, Moosianglamare in Khliehriat Civil Sub-Division, Iooksi and Shangpung under Jowai Sadar whereas Jarain and Skhentalang coalfields in Amlarem Civil Sub-Division. The areas of occurrence of coal in Garo Hills include Agalgithim, Asilgaon Hill, Balpakram, Balpakram -pendongru, Dapsi- garogithim, Dapsikhosgiri, Dogring, Holwang Baljong, Jangkhre, Kylas Hill, Mermelsaram, Nabru, Nongalbibra, Pengdengrew, Rengotim, Rongrenggirri, Rongrenggre, Siju, Singrimari, and West Darranggiri. A summary of main places of occurrence of coal in three hill regions of Meghalaya is presented in Table 2.1.

Table 2.1: Places of coal mining/occurrence of coal in three Hills regions of Meghalaya

Hill Regions	**Places of occurrence**
Garo Hills	Agalgithim, Asilgaon Hill, Balpakram, Balpakram -pendongru, Dapsi- garogithim, Dapsikhosgiri, Dogring, HolwangBaljong, Jangkhre, Kylas Hill, Mermelsaram, Nabru, Nongalbibra, Pengdengrew, Rengotim, Rongrenggirri, Rongrenggre, Siju, Singrimari, West Darranggiri.
Jaintia Hills	Bapung, Iooksi, Jarain, Khliehriat, Lakadong, Lamare, Musiang, Pamsaru, Pamsaru, Sutnga, Tkhentalang, Umlatdoh.
Khasi Hills	Cherrapunjee, Goalbari, Jarain, Jathang, Kushang, Laitduh, Laitryngew , Langkyrdem, Langrin Borsora, Lumbidon, Mawbehlarkar, Mawlong Shella, Mawmluh, Mawsynram, Moisngi, Mongokhorkhonjoy, Nongmaharu, Nongplu Nongjion, Rangsokham, Sohling, Um Bytit, Um Mawblei, Um Tongkut Wah Rangah, Wahlong.

Areas such as Bapung-Sutnga and Khliehriat in the Jaintia Hills; Cherrapunjee, Laitryngiew, Laitduh, Mawlong, Borsora Langrin etc. in Khasi Hills; and East Darrangiri, West Darrangiri, Siju, Pendengru Balpakram in the Garo Hills are the coal mining hubs in the State. Area wise distribution of coal reserves in Meghalaya is given in Table 2.2.

Table 2.2: Estimated Coal reserves at different coalfields of Meghalaya

Coalfield	Proved	Indicated	Inferred	Total (in million tonnes)
West Darangiri	65.40	-	59.60	125.00
East Darangiri	-	-	34.19	34.19
Balphakram-Pendenguru	-	-	107.03	107.03
Siju	-	-	125.00	125.00
Langrin	10.46	16.51	106.19	133.16
Mawtong Shelia	2.17	-	3.83	6.00
Khasi Hills	-	-	10.10	10.10
Bapung	11.01	-	22.65	33.66
Jaintia Hills	-	-	2.34	2.34
Total	**89.04**	**16.51**	**470.93**	**576.48**

Source: Coal Directory of India, 2014-15.

A map showing distribution of coal bearing areas/ mining areas in the state of Meghalaya prepared in the present study is presented in Figure 2.1.

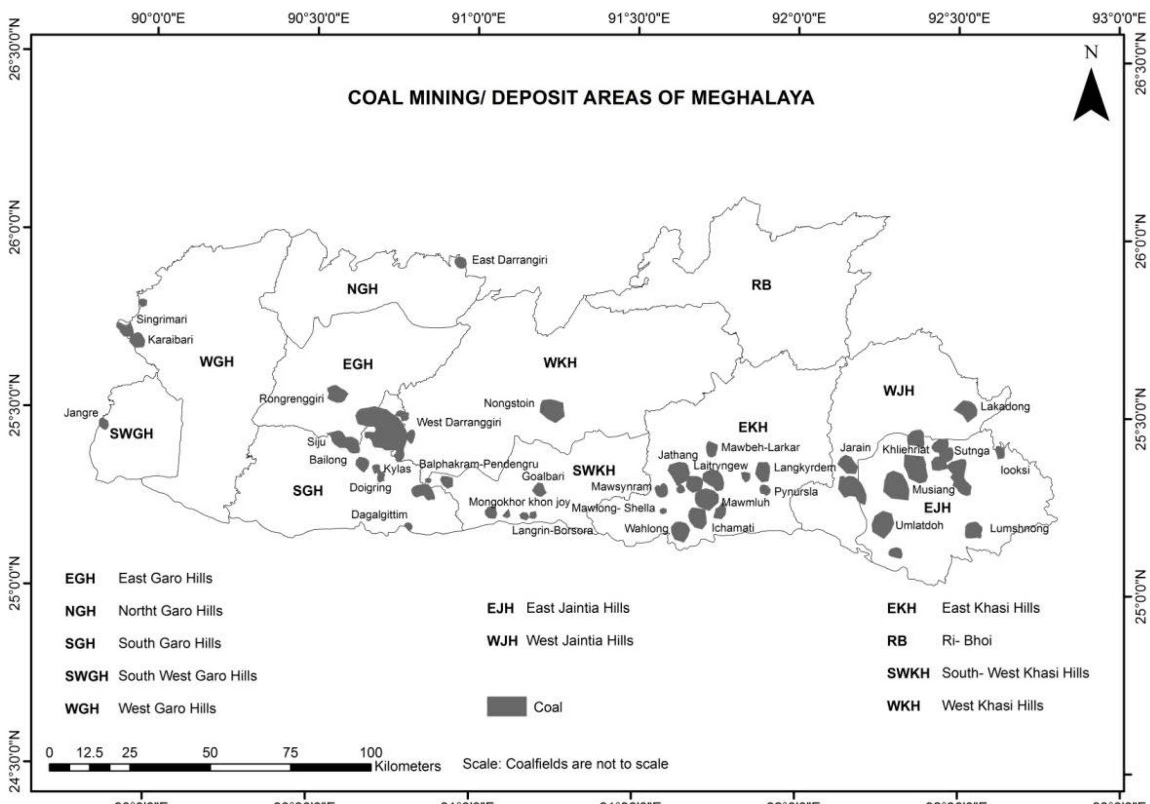

Figure 2.1: Map showing distribution of coal bearing areas/ mining areas in the State of Meghalaya

Box 2.1: Coal in Meghalaya

- The coal is one of the extensively utilized minerals in Meghalaya.
- Coal deposit in the state is found all along the southern fringe of Shillong plateau covering all three Hill regions, namely Khasi, Jaintia and Garo Hills.
- Garo Hills has the highest reserve of coal deposits followed by Jaintia Hills and Khasi Hills. However, in terms of coal production, maximum extraction has taken place from Jaintia Hills due to gentle topography and facilities developed for transport and marketing.
- Coal extraction is done by primitive mining method commonly known as 'rat-hole' mining.
- Most of the mining activities are small scale ventures controlled by individuals who own the land

2.1.2 Characteristics of Coal: The main characteristics of the coal found in Meghalaya are its low ash content, high volatile matter, high calorific value and comparatively high sulphur content. The coal of Meghalaya is mostly sub-bituminous in character. The physical properties characterize the coal of Jaintia hills district as hard, lumpy bright and jointed except for the coal in Jarain which is both soft and hard in nature. Composition of the coal revealed by chemical analysis indicates moisture content between 0.4% to 9.2%, ash content between 1.3% to 24.7%, and sulphur content between 2.7% to 5.0%. The calorific value ranges from 5,694 to 8230 kilo calories/Kilogram[2].

2.2 Limestone

2.2.1 Occurrence of Limestone

Geologically, the state of Meghalaya comprises of five different rock units namely: Pre-Cambrian gneissic complex with acid and basic intrusive, Shillong Group of rocks, Lower Gondwana rocks, Sylhet Traps and Cretaceous– Tertiary sedimentary rocks. Limestone is distributed predominantly in the southern fringe of Meghalaya plateau and falls under the rocks formation units of Cretaceous–Tertiary sedimentary rock, which is divided into three groups i.e. the Khasi group, the Jaintia Group and the Garo group. The Jaintia Group is further sub divided into three formations which include the Longpar (lower), the Shella (middle) and the Kopili (upper) formations. The Shella formation is further subdivided into six members: the upper Sylhet Limestone (Prang limestone), upper Sylhet sandstone (Narpuh

Sandstone), middle Sylhet Limestone (Umlatdoh limestone), middle Sylhet sandstone (Lakadong sandstone), lower Sylhet Limestone (Lakadong limestone) and lower Sylhet sandstone. The limestone deposited in Jaintia Hills possesses all the above three members of Sylhet limestone with alternating bands of limestone and sandstone. However, the limestone deposit in Cherrapunjee belongs to the lower Sylhet member (Lakadong limestone) of Shella formation consisting of limestone layers in the upper part of the hill and dolomite in the lower portion. Thus, the limestone rocks found in Meghalaya belong to the Shella formations of the Jaintia Group of Cretaceous –Tertiary sedimentary rocks of Eocene geological age (Sarma, 2003; DMR Profile, 2016).

Next to coal, limestone is the most abundantly found and extracted mineral in Meghalaya. Limestone rocks are sedimentary in origin and classified as non-metallic mineral with inorganic origin in nature. The two most important constituents of limestone are calcite (calcium carbonate, $CaCO_3$) and dolomite. Limestone often contain small amount of impurities such as magnesium, iron, manganese and lead. Dolomite is a carbonate of calcium and magnesium [$CaMg(CO_3)_2$].

The limestone found in different parts of Meghalaya varies in chemical composition to some extent and thus differs in quality ranging from cement to chemical grade. Generally, the CaO content of limestone found in Meghalaya is 53%. Various grades and extent of limestone rocks are found in the southern fringe of the state extending for about 200 Km from Jaintia Hills in the east to Garo Hills in the west. The maximum limestone reserve in Meghalaya is reported in Jaintia Hills (55%), followed by Khasi Hills (38%) and Garo Hills (7%). A summary of main places of occurrence of limestone in three hill regions of Meghalaya is presented in Table 2.3.

Table 2.3: Places of limestone mining/occurrence of limestone in three Hill regions of Meghalaya

Hill Region		Places/Location
1	Garo Hills	Chokpot, Darranggiri, Era Aning, Nongalbibra, Rongrenggre, Siju.
2	Jaintia Hills	Amtapoh, Lakadong, Lumshnong, Mynkree, Nongkhlieh, Nongsning, Nongtalang, Sutnga, Syndai, Thangskai, Wahiajer.
3	Khasi Hills	Borsora, Cherrapunjee, Ichamati, Langkyrdem, Mawbeh, Mawkma, Mawlong, Mawmluh, Mawsmai, Nongtalang, Pynursla, Rangsohkham, Shella, Umstew.

2.2.2 Limestone Reserves: About 9% of the country's total limestone reserves are distributed in the State. It is distributed predominantly in the southern fringe of Meghalaya plateau and falls under the rocks formation units of Cretaceous- Tertiary sedimentary rock, which is divided into three groups i.e. the Khasi group, the Jaintia group and the Garo group. Maximum reserve is in Jaintia Hills followed by Khasi Hills and Garo Hills. It is mainly distributed in the districts of East Jaintia Hills, West Jaintia Hills, East Khasi Hills, West Khasi Hills and South Garo Hills. The details of limestone reserves estimated in different parts of Meghalaya are presented in Table 2.4.

Table 2.4: Distribution of Limestone in different parts Meghalaya[2]

District/ Parts	Location	Area and Extents	Resources (in million tonnes)
East Khasi Hills	Cherrapunjee/ Sohra	1.40 sq. km. in the Mawmluh-Mawsmai Hills.	31.15
	Laitryngew	Occur as small outcrops in Umstew and Mawkma area of Laitryngew. Theband is 7.5 m. thick and traceable for about 150 m. at Umstew Cliff section.	Not estimated
	Mawlong-ishamati	13.75 sq. km. in area, 4(four) limestone bands separated by Sandstone bands are encountered. Thickness of limestone bands are of the order of 60.0,12 .0, 21.0 and 71.0 m respectively. Total thickness 244 m including both Sandstone and Limestone.	An inferred category resource of 2,166 million tonnes was reported by D.G.M., Assam. GSI has proved 395 million tonnes of resource in the area (Upper Sylhet limestone - 290 m. tones and Middle Sylhet limestone - 105 m. tonnes).
	Komorrah	The total thickness is 415m considering all limestone and sandstone bands only 0.52 sq. km. area was covered by detailed survey, where only first two limestone bands were considered.	The indicated category resource is 14.2 million tonnes (only the first two bands) and the category resource proved by drilling is 7.5 million tonnes.
	Shella	An area of 2.76 sq. km. was covered by detailed mapping where Upper Sylhet (Prang) and Middle Sylhet (Umlatdoh) limestone Members of the Shella formation were encountered. The Average thickness of the Upper and Middle Sylhet	The total indicated category resource of limestone in Shella area is 180 million tonnes of which 150 million tonnes in the Upper Sylhet limestone and 30 million tonnes in the Middle limestone beds.

		limestone Members are 60m and 20m respectively. The bands are maintaining an easterly strike with a variable dip of 80 to 400 towards south.	
West Khasi Hills	Borsora	Covers an area of 1.5km with an east-westerly extension along East-West direction and limestone bearing area is about 1.00 Sq.Km. around Borsora Village.	The indicated category resource of limestone in the above mentioned area is 3.7million tonnes.
Jaintia Hills	Lumshnong	Extends over an area of 76.8 sq.km	The inferred category resource of Upper Sylhet Limestone as reported by G.S.I. is 652 million tonnes. D.M.R., Meghalaya, indicated a resource of 291.21 million tonnes for Lower and Middle Sylhet Limestone covering an area of 2.50 sq. km., out of which 154 million tonnes of Limestone was proved over an area of 2.0 sq.km.
	Sutnga	The limestone bearing area is 9.15 m. by 75 m. in extension, (0.07 sq. km.) extended along ENE-WSW direction. Average thickness 15 m.	The indicated category resource is 2 million tonnes.
	Nongkhlieh	Covers an area of 4.01 sq. km. and the thickness range from 130m to 135m,as encountered in the borehole drilled by D.M.R., Meghalaya.	The inferred category resource is 600 million tonnes over an area of 4.1 sq. km. Proved category resource is 400 million tonnes (168 m.t. in the north block & 127 million tonnes inthe middle & 115 million in the south block over an area of 2.1 sq. km.
	Lakadong	Covers an area of 26 sq.kms.	The inferred category resource is 780 million tonnes.
	Syndai	The deposit occurs as narrow belt around Unlari and Syndai village covering an area of 2.0864 sq. kms. and the thickness of the limestone varies from 15m to 20m.	The inferred category resource is as follows (in an area of 2.08 sq. km.) (1) 26.05 million tonnes. Cement grade (2) 69.80 million tonnes. Dolomitic limestone
West Garo Hills	Darrang-eraaning	Covers an area of 1.94 sq. kms. Average thickness of upper band is 15 m and	The total indicated category resource is 47.7 million tonnes, out of which the top band

		lower one is 3m.	contains 37.70 million tonnes and the lower band contains 10.02 million tonnes.
	Siju-artheka	Covers an area of 5.70 sq. kms. Limestone occurs on both side of Simsang river. Maximum thickness 90m (Average 60m).	The indicated category resource is 229 million tonnes, out of which 27 million tonnes of cement grade limestone is proved by drilling.

Various grades and extent of limestone rocks are found in the southern fringe of the state extending for about 200 Km from Jaintia Hills in the east to Garo Hills in the west. According to Tripathi et al. (1996), the maximum limestone reserve in Meghalaya is reported in Jaintia Hills (55%), followed by Khasi Hills (38%) and Garo Hills (7%). Quality of limestone deposited in Meghalaya varies from cement to chemical grade in nature. In the Indian Mineral Yearbook (2012), it is reported that Meghalaya possesses about 9% of the country's total limestone reserve. The geographical distribution of limestone in Meghalaya is depicted in Figure 2.2.

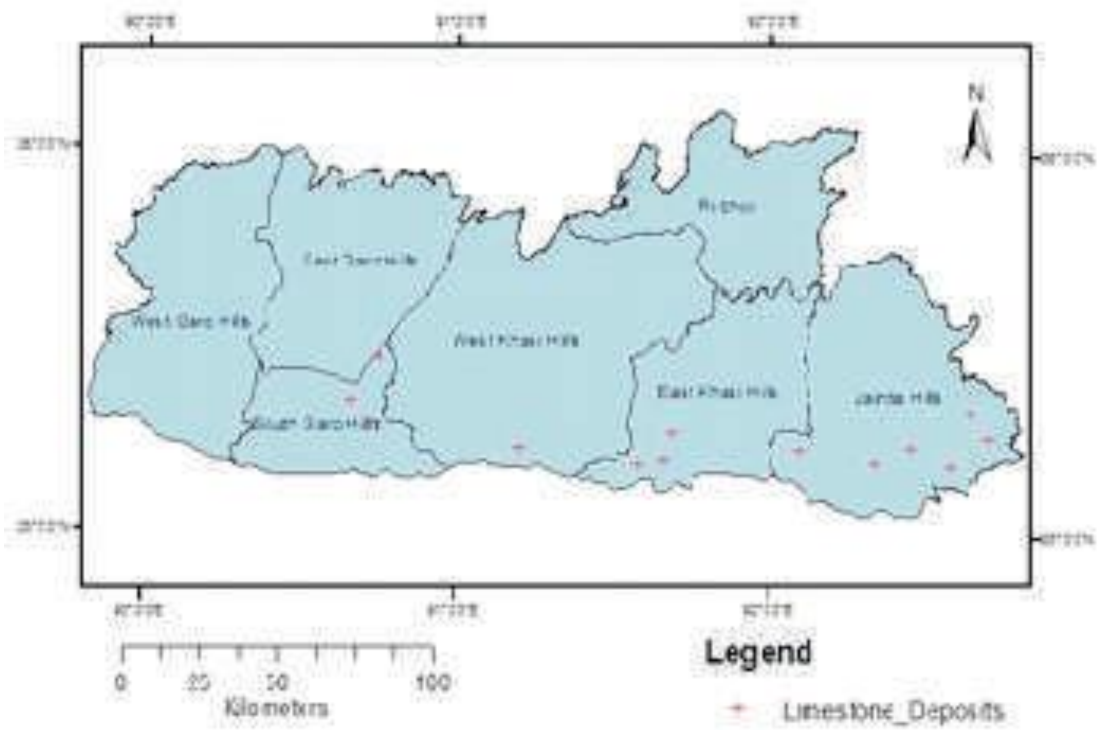

Fig. 2.2. Map showing distribution of limestone deposits in Meghalaya

A map showing distribution of limestone bearing areas/ mining areas in the state of Meghalaya prepared during this study is presented in Figure 2.3.

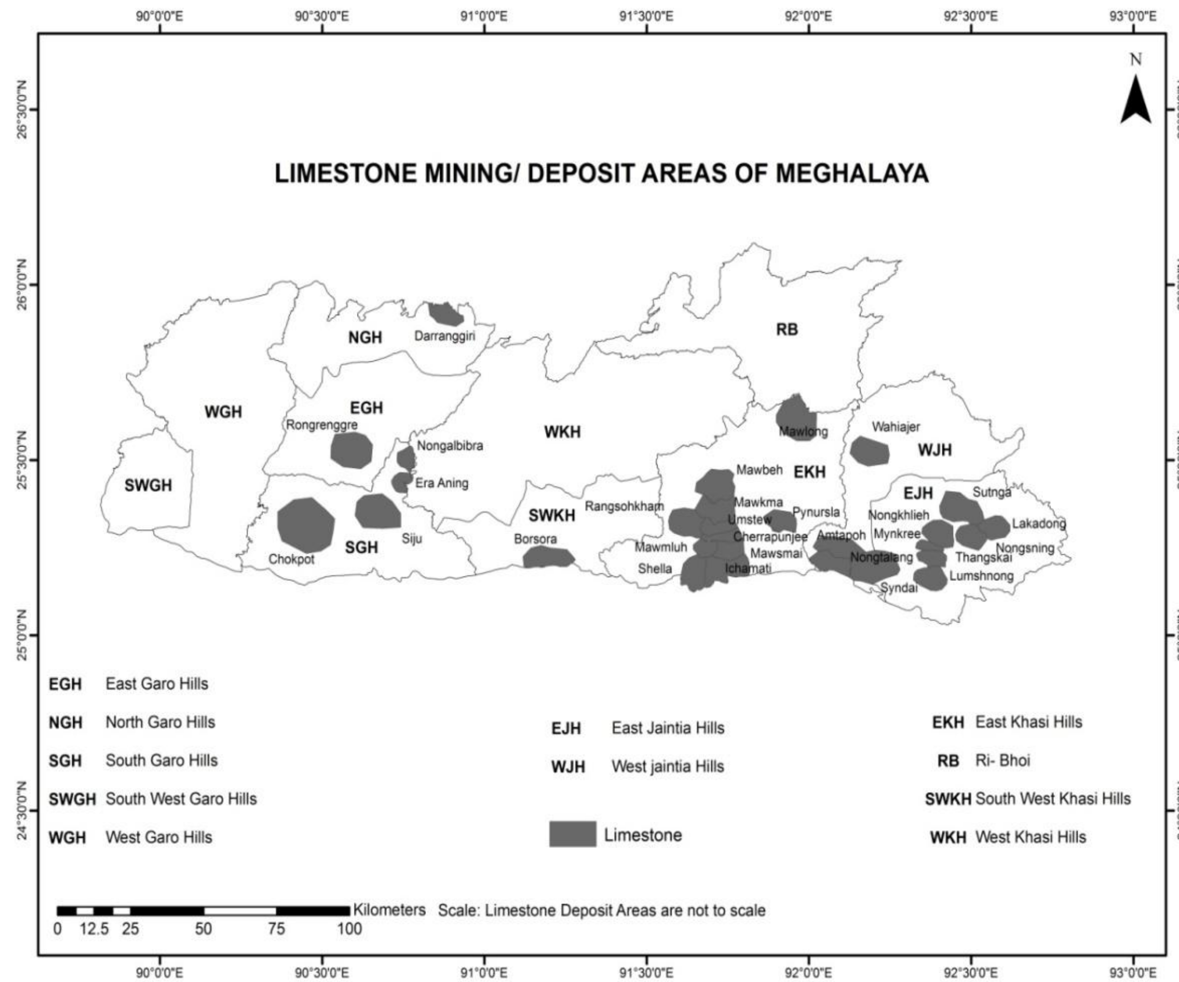

Figure 2.3: Map showing distribution of limestone bearing areas/ mining areas in the state of Meghalaya

2.2.3 Chemical Composition: The limestone found in different parts of Meghalaya varies in chemical composition to some extent and thus differs in quality ranging from cement to chemical grade in nature. Generally, the CaO content of limestone found in Meghalaya is about 50% [2] however it varies from 42% to 53% in limestones of Meghalaya It is used for various purposes such as manufacturing of cement, lime and edible lime etc. The chemical composition of limestone found in different parts of Meghalaya is summarized in Table 2.5.

Table 2.5: Chemical composition of limestone found in different parts of Meghalaya[2]

Major chemical compounds (in %)	Sample Locations in Jaintia Hills					
	Lakadong	**Lumshnong**	**Nongkhlieh**	**Nongtalang**	**Sutnga**	**Syndai**
CaO	42.27-53.89			46.33	48.75-53.09	42.00-49.60
MgO	1.25-5.58			3.51	0.72 - 3.41	0.56 - 2.07
SiO_2	0.14-3.12	40.69-54.67	40.46-53.88	-	-	-
Fe_2O_3	0.26-1.59	0.20-11.55	0.36-7.12	-	-	1.73 - 2.31
Al_2O_3	0.22-2.61	0.04-17.20	0.16-10.00	-	-	-
R_2O_3	-	0.04-3.87	0.07-4.91	-	0.48 - 5.40	-
AI	-	0.05-5.71	0.16-6.37	9.07	1.08 - 3.78	6.11-13.90
Major chemical compounds (in %)	**Sample Locations in East Khasi Hills**					
	Cherrapunjee	**Komorrah**	**Laitryngew**	**Mawlong-Ishamati**	**Shella**	
CaO	44.33-53.53	51.97-54.95	52.02-54.41	51.91-53.04	48.15-53.98	
MgO	0.33-4.21	0.76-2.98	0.15-2.25	0.43 - 4.76	0.72-6.85	
SiO_2	-	0.46-1.90	-	0.56 - 2.78	0.38-5.20	
Fe_2O_3	-	0.28-1.11	-	0.38 - 0.48	0.28-1.72	
Al_2O_3	-	0.16-0.56	-	0.26 - 1.06	0.48-2.18	
R_2O_3	0.31-2.17	-	-	-		
AI	1.43-12.39	-	3.00	-		
SO_3	-	-	-	-	Trace	
P_2O_5	-	-	-	-	Trace	
Na_2O	-	-	-	-	Upto 0.25	
K_2O	-	-	-	-	Upto 0.25	
Major chemical compounds (in %)	**Sample Locations in West Khasi Hills**	**Sample Locations in West Garo Hills**				
	Borsora	**Darrang-Era-Aning**	**Siju-Artheka**			
CaO	41.86-53.32	38.00-51.35	46.90			
MgO	0.48-6.10	0.55-4.04	1.72			
SiO_2	0.36-4.52	0.66-6.61	-			
Fe_2O_3	0.64-5.78	0.43-5.28	0.47			
Al_2O_3	1.14-6.55	0.24-27.05	2.69			

2.2.4 Limestone Mining Leases Issued in Meghalaya: In recent years, Government of Meghalaya has granted limestone mining leases to several companies for mining of limestone, its utilization and ultimately for manufacturing of cement. In addition to leases granted by the government, mining of limestone is rampant because of the unique land ownership in the state. Hence, mining in Meghalaya is predominantly in private hands. The extraction/mining of the rocks and minerals is carried out by the individual land owners in whatever way they deem fit and profitable. In most cases, the method of mining carried out was found unscientific, disruptive and degrading to the environment. Lack of reclamation responsibility and stringent regulated mining procedure further magnify the consequences of mining in Meghalaya. A list of mining leases granted in Meghalaya is given in Table 2.6.

Table 2.6: Limestone mining leases granted by Government of Meghalaya[2]

Sl. No	District	Name of Lessee	Location	Lease Period (Years)	Area in Hectare	Year Granted
1	**East Khasi Hills**	Mawmluh Cherra Cement Ltd.	Mawmluh	20	139.67	2001
		Komorrah Limestone Mining Co.	Komorrah	20	240.55	2003
		Lafarge Umiam Mining Pvt. Ltd	Nongtrai	30	100	2001
		M/S K. Singh Wann & Son	Ichamati Mawkhlain	20	4.56	2006
2	**Jaintia Hills**	M/S Adhunik Cement Ltd.	Mootang Thangskai Block -1	20	4.9	2009
			Block -2	20	4.9	2009
			Block -4	20	4.9	NA
		M/S JUD Cement LTD	Wahiajer Narpuh	30	4.76	2009
		Cement Manufacturing Co. Ltd	Lumshnong	20	4.96	2005
				20	4.7	2006
				20	4.85	2006
		Meghalaya Cement Ltd	Moiong, Chiehruphi	20	4.8	2007
			Khliehjri, Thangskai	20	4.9	2006
3	**West Khasi Hills**	Anderson Mineral Pvt. Ltd	Lalghat Cherragoan	20	60	2007

Source: Directorate of Mineral Resources Portal, Government of Meghalaya (2016)

Though, mining of coal and limestone in Meghalaya (coal mining in Jaintia Hills and Khasi Hills and limestone mining in Khasi Hills) started in the second half of 19th Century during British period, it was only in seventies of twentieth century that mining began to flourish. Suddenly, Jaintia Hills was recognized as a rich coal belt in Meghalaya. At that time, extracted coal was mainly supplied and marketed to Silchar to tea estates and brick kilns. In the 1980s, large-scale commercial mining of coal started in the area and extensive exploitation of coal was carried out in Jaintia Hills. Similarly, large scale mining of limestone in Cherrapunjee for the production of cement started quite early, but drastic expansion of limestone mining took place in Jaintia and Khasi Hills in the first decade of this century after establishment of large number of Cement Plants in the state. Thereafter, mining of both coal and limestone are taking place in all three Hills regions of Meghalaya and has become an important source of income and employment in the state.

Owing to the unique land holding system and property rights prevailing in the State, there was hardly any role of the Government in allocation and acquisition of land for mining purposes. The mine owners have unlimited access to extraction of minerals without any regulation. The Mines and Minerals (Development and Regulation) Act, 1957 and various Environmental Acts applicable to mining sector in other parts of the country have not been implemented before July 2019 in the shadow of Sixth Schedule of the Indian Constitution. However, no any such exemption has been granted by the Central Government or any other agency. Owing to all these, mining became a preferred investment option and has attracted many to this business and rampant unregulated mining of coal took place in Meghalaya adversely affecting the environment, flora and fauna, natural resources, traditional livelihood and human health. However, in July 2019 the Honourable Supreme Court of India brought the mining of minerals in Meghalaya under the ambit of Mines and Minerals (Development and Regulation) Act, 1957 and other Acts applicable to mining sector in India.

3. Mining of Minerals in Jaintia Hills

Of several minerals found in Jaintia Hills, only coal and limestone have been mined in large areas. Other minerals are distributed in small patches in the State and mostly they remain un-mined. As a result only coal and limestone have yielded significant revenue for the State. The details of coal mining taking place in Jaitia Hills are discussed below.

3.1 Coal Deposits and Coal Mining in Jaintia Hills

3.1.1 Coal Deposits in Jaintia Hills

The major coal bearing areas of Jaintia Hills District are Sutnga, Lakadong, Musiang-Lamare, Khliehriat, Ioksi, Ladrymbai, Rymbai, Bapung, Jarain, Shkentalang, Lumshnong and Sakynphor (Figure 3). A brief description of major coalfields of Jaintia Hills is given below:

Bapung: Bapung lies in the south-eastern part of Jaintia hills district and falls in the toposheet No. 83 C/7. The NH-44 passes through Bapung and Khliehriat from north-west to south-east.Bapung is located at a distance of 24 km from Jowai (the district headquarters Jaintia Hills), and 97 km from Shillong (the state capital) along the Jowai–Badarpur Road. The area exhibits undulating surface with gentle slopes trending towards south. There are three coal seams covering an area of 46 km^2. The nature of coal deposit is bedded type and the coal occurs in the Lower Sylhet Sandstone Member of Eocene Age. The thickness of the seams varies from 0.3 metres to 1.2 metres. The coal reserve of this area is 33.66 million tonnes as estimated by the Directorate of Mineral Resources, Govt. of Meghalaya (1974).

Lakadong: Lakadong is about 59 kms from Jowai and can be approached by a road through Khliehriat. The area is divided into two coalfields namely the Umlatdoh and Pamsaru coalfields. Coal deposit here is again of bedded type and coal occurs in the Middle Sylhet Sandstone Member of the Shella Formation. The Umlatdoh coalfield covers an area of 1.04 km^2 with a thickness of 0.3 metres to 2.12 metres. The possible reserve is estimated at 470,000 tonnes. The Pamsaru coalfield, situated about 1.62 km to the north-east of Umlatdoh has coal seams of 1.10 metres thickness.

Jarain and Tkentalang: Jarain and Tkentalang are situated about 22 km in the south-western part of Jowai and can be approached by a fair weather road. The area exhibits flat topped hills. In Jarain, there is only one coal seam with a thickness of 0.3 to 1.10 metres covering an area of 2.8 km^2 whereas there are two coal seams in Tkentalang which is about 3 kms north of Jarain. The top coal seam is 0.10 to 0.15 metres thick and the bottom seam is 0.30 to1.00 metres in thickness. The nature of coal deposit is bedded type. Coal occurs in the Lower Sylhet Sandstone Member of the Eocene Age. The total inferred reserve is 1.1 million tonnes

Sutnga: Sutnga, about 74 km from Jowai is located in the North–eastern direction of Lakadong. Sutnga coalfield is the eastern extension of Bapung coalfield and it has two coal seams which covers an area of 160,579 sq metres. Coal deposit is of bedded type and coal occurs in the Lower Sylhet Sandstone Member of Eocene age. The top coal seam is 0.10 to 0.20 metres in thickness and the bottom seam is 0.3 to 0.60 metres in thickness. The inferred reserve estimated is 0.65 million tonnes.

Musiang-Lamare: Musiang Lamare coalfield occurs near Lumshnong of Jaintia Hills District. This coalfield covers an area of 2.31 km^2 with a coal seam of thickness varying from 0.15 to 0.65 metres. The nature of coal deposit is bedded type and the coal occurs in The middle Sylhet Sandstone of Eocene Age, overlain by the Umlatdoh Limestone. The inferred reserve is 1.1 million tonnes as estimated by Directorate of Mineral Resources, Govt. of Meghalaya.

Ioksi: Ioksi is located near Garampani. Coal here occurs in an area of 3.6 km^2 with an average seam thickness of 0.80 m. The nature of coal deposit is bedded type. The coal here occurs in the Lower Sylhet sandstone of Eocene age. The inferred reserve as estimated by the Directorate of Mineral Resources, Govt. of Meghalaya is 1.24 million tonnes.

Lumshnong: Lumshnong is located near Musiang-Lamare. Coal here covers an area of 0.6km to the west and south-west of Lumshnong. The seam thickness varies from 0.3m to 0.6m.

Mutang: Mutang is located about 1.6km south-west of Malwar. Coal seam thickness varies from 0.25m to1.08m. The coal type here is similar to that found in Sutnga.

3.1.2 Coal type and its Composition

The Tertiary coal deposits of Meghalaya, belonging to Eocene age, are found mostly on the southern slopes of the State. The main characteristics of the coal obtained here are its low ash content, high volatile matter, high calorific value and comparatively high sulphur content. The coal is mostly sub-bituminous in character. The physical properties of the coal in Jaintia Hills District shows that the coal is mostly hard, lumpy bright and jointed except for the coal in Jarain which is both soft and hard in nature. Chemical composition of the coal indicates that the moisture content varies from 0.4% to 9.2%. The ash content ranges from a minimum of 1.3% to a maximum of 24.7%. The sulphur content ranges from 2.7% to 5.0%. The calorific value ranges from 5,694 to 8230 kilo calories/Kilogram.

3.1.3 Unscientific and Primitive Method of Mining of Coal

Though, small scale mining of coal existed during pre-independence period mainly for the purpose of heating and local use by blacksmiths, however mining of coal stopped later due to non-availability of uses. Mining of coal started again in the beginning of 1970s and gradually acquired status of a major business in Meghalaya in Jaintia, Khasi and Garo Hills regions.

Coal mines all over the county were nationalized by an Act passed by the Parliament, (Coal Mines Nationalization Act, 1973), and subsequently brought under Coal India Limited. But coal mines in Meghalaya operate without giving any consideration towards the Coal Mines Nationalization Act 1973. Various provisions of The Mines and Minerals (Development and Regulation) Act, 1957 and different environmental acts have also been ignored in coal mining sector of Meghalaya.

Large-scale coal mining began from 1980s onwards in Meghalaya and Jaintia Hills region was recognized as a major coal producing area. Since then a huge unscientific exploitation of coal has been taking place in all three Hills regions of Meghalaya, without obtaining any permission from any authority, including environmental clearance, and often without taking any safety measures for the mining workers. In recent decades coal was marketed and transported to different parts of India and also exported to Bangladesh.

The coal mining in Meghalaya is small scale and an unorganized venture controlled by individuals, who own the land. Many land owners lease out their land to miners who arrange finances, implements, workers, transporters etc. and undertake extraction of coal. However, collectively coal mining engaged thousands of people in mining and mining related activities spread in a wide area of all three Hill Regions of the State before imposition of ban by National Green Tribunal (NGT) in 2014.

Coal extraction in Meghalaya is done by primitive mining method commonly known as ‘rat-hole’ mining. The method of extraction of coal depends on the location and orientation of the coal seams. The coal deposits present on the hill-slopes and along the river sides are approached by ‘side-cutting’, in which coal seam is reached by excavating the side edge of the hill slopes and then coal is extracted by making a horizontal narrow tunnel (rat hole) through the coal seam. In plain land the coal deposit is reached through a pit by ‘box cutting’ method. In this method the land is, first cleared by cutting and removing the ground vegetation and then pits ranging from 5 to 100 square meters are dug into the ground to reach the coal seam. Thereafter, tunnels are made into the seam sideways to extract coal which is first brought into the pit and then taken out and dumped on open area. The extracted coal is then transported near the highways for its sale. In this process a large area of the land is spoiled and denuded due to movement of heavy equipments like bulldozers, tractors, trucks and cranes. The overburden in the form of rocks and soil generated while digging the pit is dumped near the mining site.

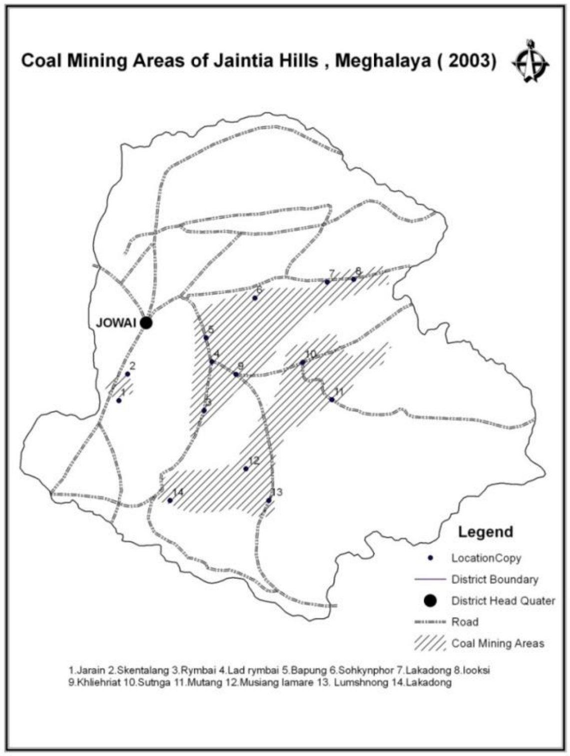

Figure 3.1a: Coal Mining areas in Jaintia Hills in 2003

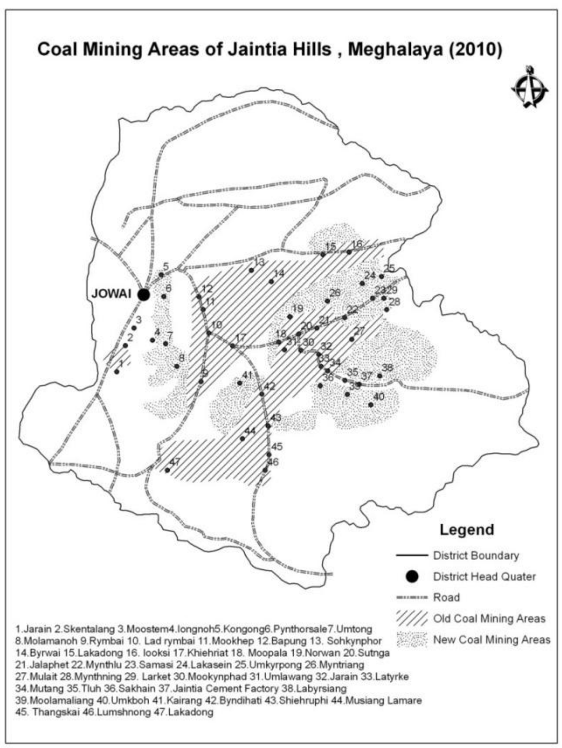

Figure 3.1b: Coal Mining areas in Jaintia Hills in 2010

Unfortunately, during the past a couple of decade the area is under extensive coal mining. The present modus operandi for coal extraction is unscientific and aggravating the ecological and environmental problems. Coal mining area in Jaintia Hills is increasing in extent year after year as shown in Figures 3.1a and 3.1b for the years 2003 and 2010. Photographs of a coal mine, mining activity and coal dumps are presented in Figures 3.2.

Figure 3.2: Photographs of a coal mine, mining activity and piles of mined coal in Jaintia Hills

Figure 3.3: Imagery showing coal mining area of Jaintia Hills. The lower panel is magnified view where coal mine pits (indicated by arrows) are visible clearly. (Source: Google Map)

Box 3.1: Rat hole mining in Meghalaya

- Coal in Meghalaya being found deposited in thin seams imbedded in sedimentary rocks, sandstones and shale is mined by making tunnels through the coal seam. The tunnels being narrow are referred to as 'rat holes' and the mining method is commonly known as 'rat hole mining'.

- The Tertiary coal deposits of Meghalaya, belonging to Eocene age, are found mostly on the southern slopes of the State. It is of Sub-bituminous type.

- The main characteristics of the coal are its low ash content, high volatile matter, high calorific value and comparatively high sulphur content.

- Miners approach coal seam by making tunnel either through side of the hills or through a rectangular shaft/pit. Based on the approach route, the rat hole mining methods have been referred to as 'side-cutting' or 'box-cutting'. In 'side-cutting' rat hole mining a hole is cut from the side of the hill where coal seam is visible from outside or there is possibility of coal seam located inside. Through a narrow tunnel the miners explore the inside of the hill for coal and if found extract it manually through small implements. In 'box-cutting' method the land is, first cleared by cutting and removing the ground vegetation and then pits ranging from 5 to 100 m^2 are dug vertically into the ground to reach the coal seam. The depth of the vertical shaft varies from 20 m to 130 m depending on the depth of the coal seam. Thereafter, horizontal narrow tunnels are made into the seam. The height of the tunnel, in most cases is about 3 to 4 feet due to thin coal seams.

- In both methods (side-cutting or box-cutting) the miners enter/crawl into the tunnel and mine the coal with small shovel. The extracted coal is brought from the tunnel into the shaft/pit by using a low height wooden wheel barrow. The coal is then taken out of the pit either manually or with the help of a small crane. The extracted coal is dumped on nearby area, from where it is carried to the larger dumping places near road/highways for its trade and transportation.

3.2 Limestone Deposits and Mining in Jaintia Hills

The history of limestone mining in Khasi Hills of Meghalaya seems very old. As per the Assam District Gazetteers published in 1906, limestone quarrying and trading in Khasi Hills have existed as early as in eighteenth century and it was a lucrative business to the people of Sylhet (presently in Bangladesh) and Khasi Hills of Meghalaya (then Assam). Thus, limestone mining in Meghalaya is taking place for long time, however earlier it was at small scale and for local uses only mainly for the production of edible lime. Later, limestone was used for the production of cement on establishment of cement manufacturing industries in

Meghalaya. The Mawmluh-Cherra Cements Limited (MCCL) was the first cement manufacturing unit in the state. It was originally established by some unknown industrialists in Cherrapunjee in 1955 under the banner name of Assam Cements Limited. In Sohra (Cherrapunjee), limestone is also extracted at small scale level. The small scale extraction of limestone is done manually by individuals using minimal machinery and thus categorized as Artisanal and Small Scale mining (ASM).

The limestone mining in Jaintia Hills started relatively late for commercial purposes. The Jaintia Cement Limited was the first private cement manufacturing plant established in Sutnga Village in 1986. Extensive mining of limestone in Jaintia Hills, Meghalaya started after 2004 after establishment of Cement Manufacturing Company Limited (Star Cement) in Lumshnong and then other privately owned cement manufacturing units in the area. The limestone mined form Meghalaya is also transported to Bangladesh via a 17 Km long cross border Conveyer belt by Lafarge Surma Cement Ltd. In recent years, Government of Meghalaya has also granted limestone mining leases to several companies for mining of limestone, its utilization and ultimately for manufacturing of cement.

Limestone extraction in Meghalaya is carried out by open cast method of mining. It is taking place at both large scale and small scale levels. The large scale extraction of limestone is taking place in Jaintia Hills mainly for the manufacturing of cement. While both large scale and small scale mining are in practice in Sohra for production of cement, quicklime and edible lime. The areas where active mining of limestone in Meghalaya is taking place are villages like Nongsning, Mynkree, Thangskai, Wahiajer, Lumshnong, Sutnga, Lakadong, Syndai of East Jaintia Hills; Cherrapunjee and Shella of East Khasi Hills; and also in Nongtalang and Amtapoh of West Jaintia Hills. Photographs showing limestone deposit and mining activity can be seen in Figure 3.4.

Figure 3.4: Photographs showing limestone mining activities

The origin of limestone mining in Jaintia Hills of Meghalaya is not very well documented. The Jaintia Cement Limited was the first private cement manufacturing plant established in Sutnga Village in 1986. Extensive mining of limestone in Jaintia Hills, Meghalaya started after 2004 after establishment of Cement Manufacturing Company Limited (Star Cement) in Lumshnong and then followed by other privately owned cement manufacturing units in the area. Limestone extraction in Meghalaya is carried out by open cast method of mining. It is taking place at both large scale and small scale levels. The large scale extraction of limestone is taking place in Jaintia Hills mainly for the manufacturing of cement.

The mining in Jaintia Hills is mostly done by cement industries. However, due to unique land holding system in Meghalaya, mining of limestone is also carried out by individual land owners. The mining process carried out by the cement industries is efficient being mechanical using heavy machinery for excavation. On the other hand, extraction by individual land owners is semi-mechanical and slow. Generally, extraction of limestone involves mechanical removal of overburden (using bulldozers), manual drilling the blast holes, blasting of rocks, manual shattering (sizing) of the lime stone rock and then finally loading and transportation of limestone to the cement plants. Some photographs showing open cast mining of limestone in Meghalaya are presented in Figure 3.5.

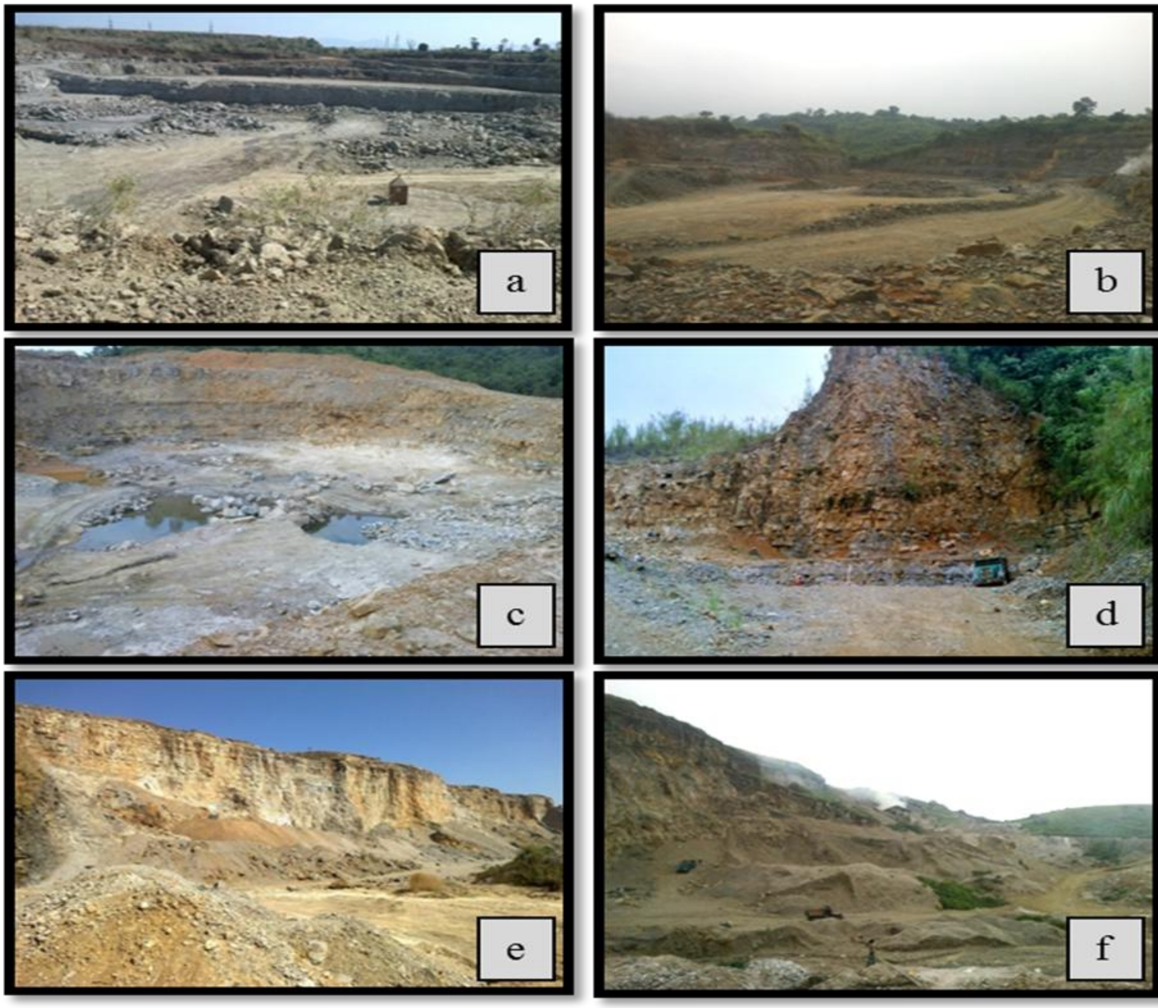

Figure 3.5: Photographs showing open cast mining of limestone done by (a, b) cement companies; (c, d) locals in Jaintia Hills; (e, f) ASM limestone mining in Sohra, Meghalaya.

In last one and half decades a number of cement plants have been established in Meghalaya with maximum numbers found in Jaintia Hills alone. Presently, the cement plants are the main consumers of limestone rocks found in the state. The cement manufactured in Meghalaya is utilized in the state as well as transported to other states of the country. A list of cement plants operating in Jaintia Hills, Meghalaya is given in Table 3.1. However, a list limestone mining leases granted by Government of Meghalaya for mining of limestone in Jaintia Hills is given in Table 3.2.

Table 3.1: List of Major Cement Plants operating in Jaintia Hills, Meghalaya

Sl. No	Company Name	Brand Name	Group	Location/Village (District)
1	Adhunik Cement Ltd	Adhunik Cement	-	Thangskai, (EJH)
2	Amrit Cement Industries Limited	Amrit Cement	Amrit Group	Umlaper, (EJH)
3	Cement Manufacturing Company Limited	Star Cement	Shyam Group	Lumshnong, (EJH)
12	Cosmo Cement Ltd.	Cosmo Cement	-	Nongkhlieh, (EJH)
13	Goldstone Cement Ltd.	Goldstone Cement	-	Musiang Lamare, (EJH)
4	Green Valley Industries Limited	Max Cement	GNG Group	Nongsning, (EJH)
5	Hill Cement Company Limited	Taj Cement	-	Mynkree, (EJH)
6	Jaintia Cement Limited	Jaintia Cement	-	Sutnga, (EJH)
7	Jud Cement Limited	Best Cement	Ud Group	Wahiajer, (EJH)
8	Meghalaya Cement Limited	Topcem	Prithvi Group	Thangskai, (EJH)

NB: EJH- East Jaintia Hill

Table 3.2: Limestone mining leases granted by Government of Meghalaya for limestone mining in Jaintia Hills

<table>
<tr><th>Region</th><th>Name of Lessee</th><th>Location</th><th>Lease Period (Years)</th><th>Area in Hectare</th><th>Year Granted</th></tr>
<tr><td rowspan="10">Jaintia Hills</td><td rowspan="3">M/S Adhunik Cement Ltd.</td><td>Mootang Thangskai Block -1</td><td>20</td><td>4.9</td><td>2009</td></tr>
<tr><td>Block -2</td><td>20</td><td>4.9</td><td>2009</td></tr>
<tr><td>Block -4</td><td>20</td><td>4.9</td><td>NA</td></tr>
<tr><td>M/S JUD Cement LTD</td><td>Wahiajer Narpuh</td><td>30</td><td>4.76</td><td>2009</td></tr>
<tr><td rowspan="3">Cement Manufacturing Co. Ltd</td><td rowspan="3">Lumshnong</td><td>20</td><td>4.96</td><td>2005</td></tr>
<tr><td>20</td><td>4.7</td><td>2006</td></tr>
<tr><td>20</td><td>4.85</td><td>2006</td></tr>
<tr><td rowspan="2">Meghalaya Cement Ltd</td><td>Moiong, Chiehruphi</td><td>20</td><td>4.8</td><td>2007</td></tr>
<tr><td>Khliehjri, Thangskai</td><td>20</td><td>4.9</td><td>2006</td></tr>
</table>

Source: Directorate of Mineral Resources Portal, Government of Meghalaya (2016)

In addition to leases granted by the government, mining of limestone is rampant because of the unique land ownership in the state. Hence, mining in Meghalaya is predominantly in private hands. The extraction/mining of the rocks and minerals is also carried out by the individual land owners in whatever way they deem fit and profitable. The mining process carried out by the cement industries is efficient being mechanical using heavy machinery for excavation. On the other hand, extraction by individual land owners is semi-mechanical and slow. Generally, extraction of limestone involves mechanical removal of overburden (using bulldozers), manual drilling the blast holes, blasting of rocks, manual shattering (sizing) of the limestone rock and then finally loading and transportation of limestone to the cement plants. In most cases, the method of mining carried out was found unscientific, disruptive and degrading to the environment. Lack of reclamation responsibility and stringent regulated mining procedure further magnify the consequences of mining in Meghalaya.

Box 3.2. Limestone in Meghalaya

- Next to coal, limestone is most abundantly found and extracted mineral in Meghalaya
- About 9% of the country's total limestone reserves are distributed in the state.
- Limestone is found in all three hills regions (Khasi, Jaintia, Garo) of Meghalaya.
- The Limestone found in different parts of the Meghalaya varies in chemical composition and thus differs in quality from cement to chemical grade.
- Limestone is extracted by opencast mining mainly for manufacturing of cement in Jaintia Hills.

3.3 Sand and Stone Mining

Sand and stone mining is also taking place from riverbed and hill sides to cater the local needs in the state as well as of neighboring state. Mostly these resources are collected from the riverbed after the rainy season when water level of rivers is low. However, mining from hill sides continues throughout the year depending on local needs. Sand and stone mining from the hills and river beds are taking place unabated in all three Hill regions of Meghalaya.

Other minerals are distributed in small patches in Meghalaya and mostly they remain un-mined. Thus, coal and limestone have been mined extensively in Meghalaya and have contributed significant revenue for the State and the private mine owners.

4. Water Resources of Jaintia Hills

The rainfall is the source of all water present in Meghalaya, including the Jaintia Hills region. The rainfall in Jaintia Hills is directly controlled by the southwest monsoon originating from the Bay of Bengal and the Arabian Sea. The area receives a fairly high rainfall. The average annual rainfall in Jaintia Hills is about 4173 mm recorded at Rymphum seed farm in Jowai. Most of the precipitation occurs between April and October. The monthly maximum rainfall of 2655.80 mm was recorded in June 1995 at the same rain gauge station. The lowest annual rainfall was recorded in 2009 with 2623 mm and the highest annual rainfall was recorded in 1995 with 7695 mm.

4.1 Hydrogeology

Hydrogeologically, the Jaintia Hills region can be divided into three units, namely consolidated, semi consolidated and unconsolidated formations.

Consolidated formation: These include the oldest rock formation occupying about 1300 km^2 in the northern and western parts. Peneplaned gneissic complex, quarzites etc. constitute this unit. The depth of weathering varies from place to place and is 15 to 20 m at most places. The presence of substantial-weathered mantle is confined to their secondary porosities, which form excellent repository of ground water in hard rocks area. The storage and movement of ground water in hard rock is controlled by physiography, zone of weathering and interconnected places of weakness. Ground water occurs under unconfined condition and in semi-confined condition in the interconnected secondary structural weakness/ features like joints, fractures etc. of the underlying hard rocks. The depth to water level varies between 0.13 to 1.13 m bgl.

Semi consolidated formation: This constitutes a major part of the Jaintia Hills region covering Amlarem and Khliehriat blocks and covers two- thirds of the entire area. It ranges in age from late Cretaceous to Plio- Pleistocence. The shella formation of the Jaintia group is the most conspicuous. Ground water in this formation occurs under unconfined to semi confined conditions due to primary porosities of the semi consolidated formations as well as in the secondary porosities like caverns, open fractures and joints. The formations show both isolated hammocky topography to highly undulating topography with steeply rising hills and deep gorges. The karst topography is observed in areas of Letein, Latyrk, Litang etc. occupied by the cavernous limestone. The depth to water level lies between 0.30 and 1.13 m bgl.

Unconsolidated formation: The unconsolidated formation is mainly represented by recent alluvium which occurs near the southern fringe of the region and is the continuation of the alluvial plain of Bangladesh. It constitutes of about 67 km^2 representing about 2% of the total area. The hydrogeological map of Jaintia Hills is presented in Figure 4.1.

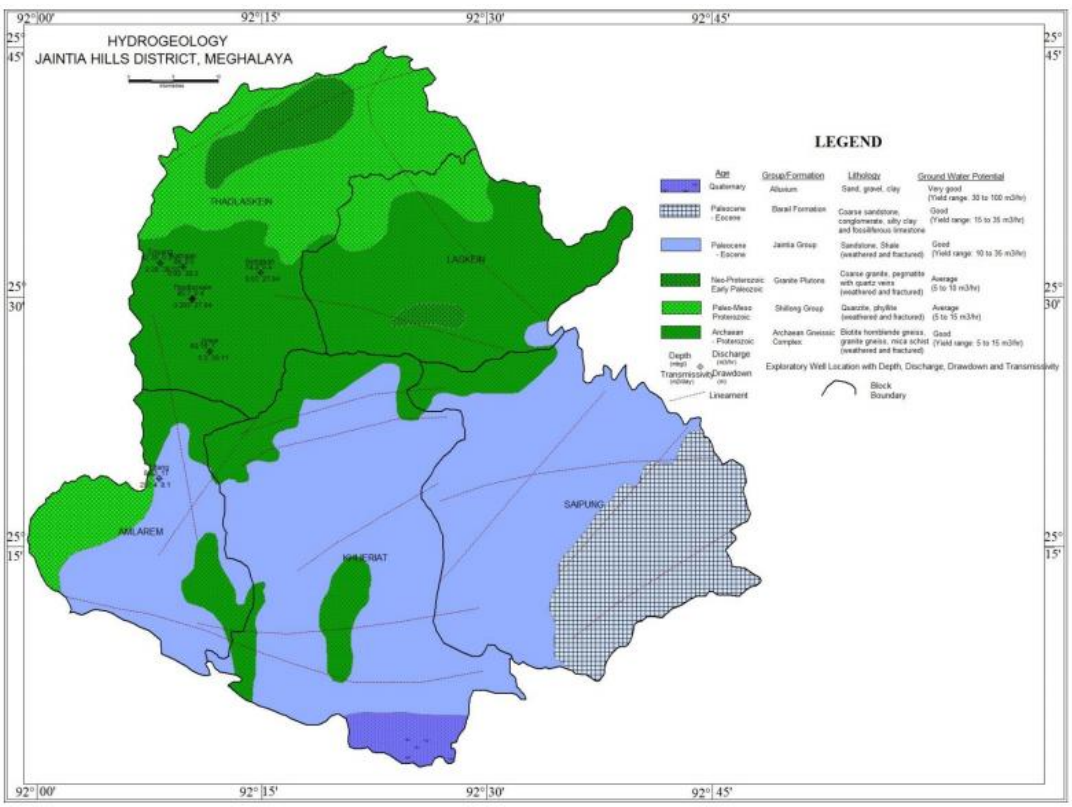

Figure 4.1: Hydrogeological map of Jaintia Hills
(Source: http://cgwb.gov.in/District_Profile/Meghalaya/Jaintia%20Hills.pdf)

The Jaintia Hills region can be divided in to 4 river sub-basins which take water to all four directions esta, west, north and south. The four river sub-basins are Myntdu, Kopili, Umiam and Umngot. The map showing demarcations of four river sub-basins in Jaintia Hills is presented in Figure 4.2.

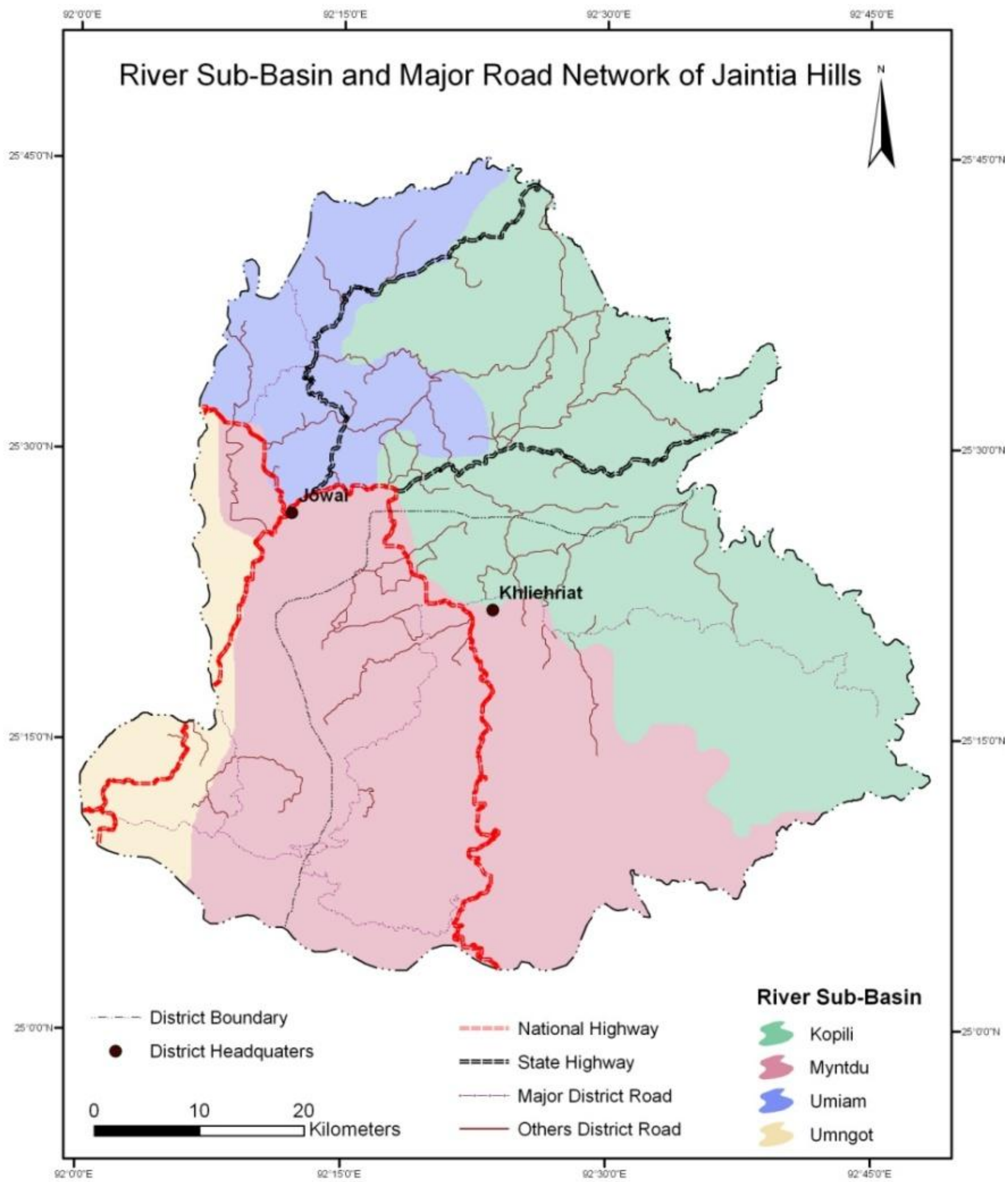

Figure 4.2: River sub-basins of Jaintia Hills

4.2 Drainage

A large number of rivers and streams drain the undulating landscape of the Jaintia Hills. Most of these rivers and streams flow towards south-east into the flood plains of Bangladesh. However, a few also flow towards northern side into the Brahmaputra valley.

The drainage system of the district is controlled by topography. Broadly, there are mainly two watersheds in the district, one river flowing in the northern direction toward the Brahmaputra and the other in the south, towards the Surma valley in Bangladesh. The important rivers flowing to the Brahmaputra are Kopili, Myntang and Mynriang and the main rivers flowing to the Surma valley are Myngngot (Umngot), Myntdu, Wah Prang, Wah Lukha and Wah Simlieng. The drainage pattern is sub parallel to parallel. It is being controlled by joints and faults as indicated by the straight courses of the rivers and streams with deep gorges. The map showing drainage pattern of the State is goven in Figure 4.3.

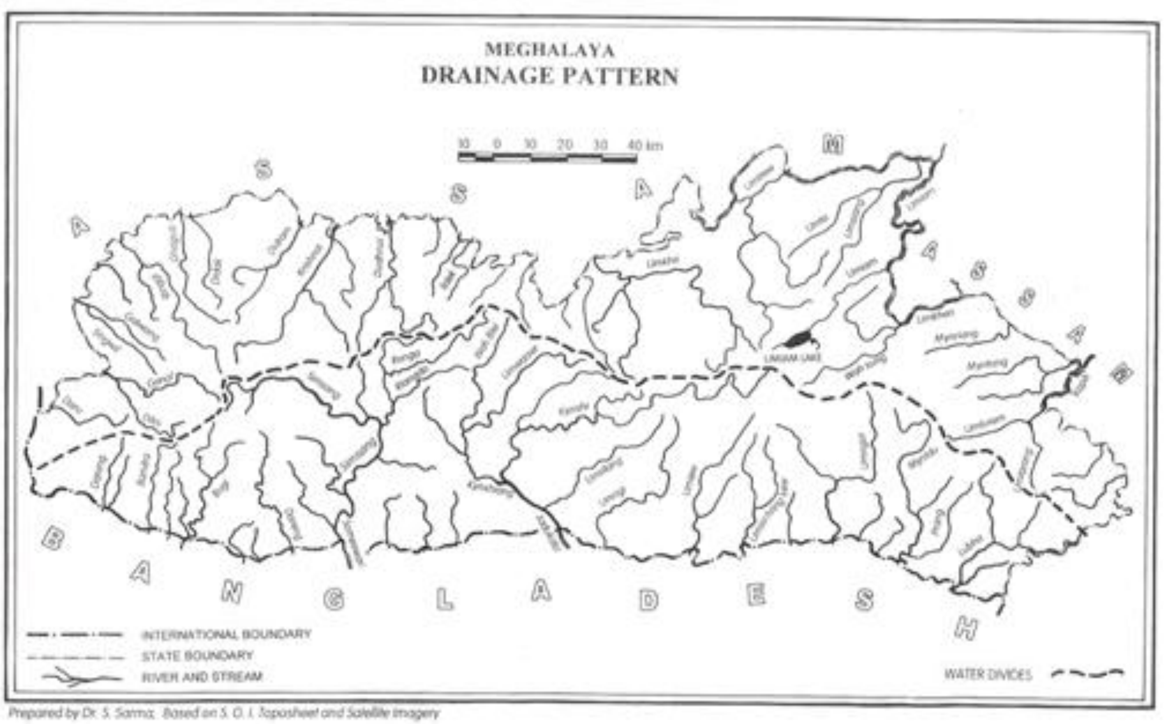

Figure 4.3: Drainage map of Meghalaya

4.3 Major Water Bodies

A dense network of streams and rivers drain Jaintia Hills, Meghalaya. They flow either towards Brahmaputra River in the east north direction or in the Surma valley of Bangladesh in the south. A map showing major rivers and streams in Jaintia Hills is presented in Figure 4.4.

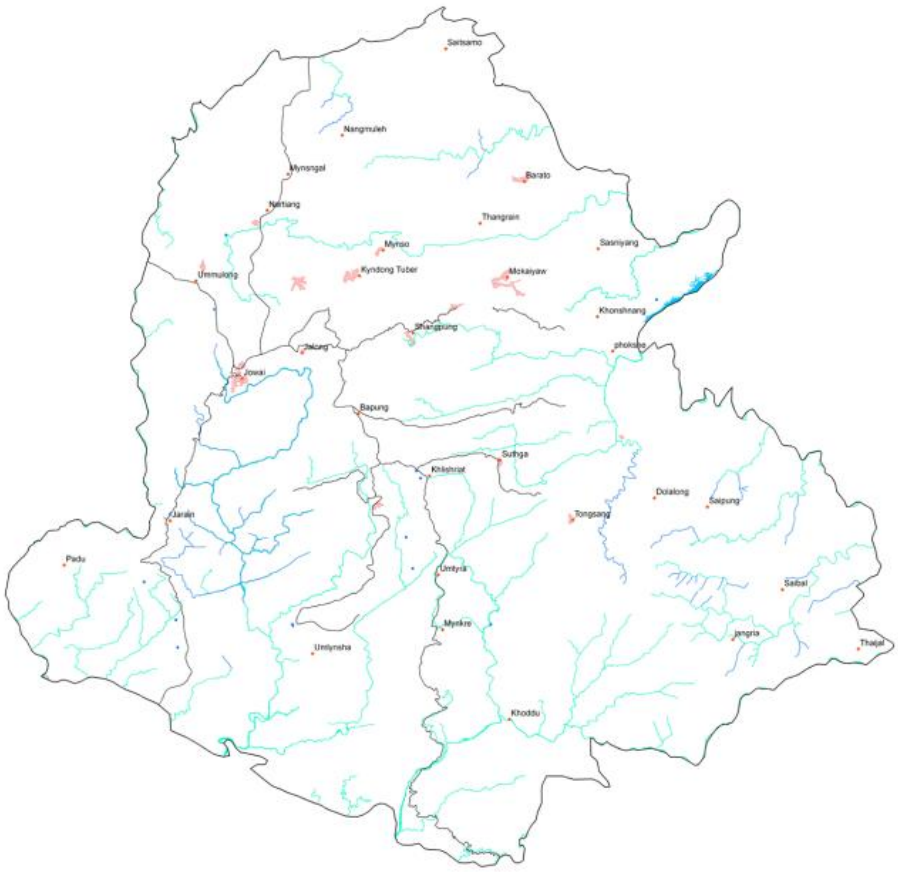

Figure 4.4: Map showing major rivers in Jaintia Hills, Meghalaya[8]
(Source: North Eastern Space Applications Centre, Umiam, Meghalaya)

The major water bodies in Jaintia Hills are Myntdu, Prang, Lukha and Lubha rivers which flow into the Bangladesh plain. River Myntdu originates near Jowai, the district headquarters, and flows towards Bangladesh where it is known by the name "Hari". It surrounds Jowai town from three directions, i.e., East, West and South leaving open the North. River Lukha originates from Sutnga and flows towards Bangladesh plains. Prang river is called Seshympa river in the upper part of the area. This river joins Myntdu river in the south which together flow towards Bangladesh plain. River Lubha is located near river Lukha and flows through Sonapur village towards Bangladesh plains. In the eastern side of the district are tributaries of river Kopli namely, river Mynriang, river Umiurem and river Myntang. River Mynriang originates near Nongjing Elaka about 24 kms from Jowai and river Umiurem originates near Pasyih and Muthlong which are situated in the Western side of Shangpung about 32 kms from Jowai. Flowing through Nartiang to Mynso, river Myntang originates near Lalong village which is about 8 kms from Jowai. Besides these, river Umtarang also drains the eastern side of the district. These rivers flow towards Brahmaputra valley in Assam. River Kopli is the biggest river in Jaintia Hills. The river originates from the black mountains of Lum Bah-bo Bah-kong and flows northward into the Brahmaputra valley. This river demarcates Jaintia Hills and North Cachar hills of Assam.

Some other rivers in coal mining are Kmai-um and Rawaka of Rymbai, Thwai Kungor of Bapung, Brilakam of Myrsiang, and Mynsar of loksi. A few streams namely Wah Bapung of Bapung, Umthalan of Lakadong, Mynkien of Jarain, Saitpathi of Sutnga, and Metyngka of Rymbai are also located. The Wah Waikhyrwi (Um Roong) and Sarbang are the main rivers flowing through Sutnga area. Besides, there are a number of streams, which flow through narrow valleys. In Jarain Shkentalang area, streams flowing towards east are Um Laho, Thlumwi, and Um Pilang and towards south Umladkhur.

5. Impact of Mining on Water Resources in Jaintia Hills

Mining and exploitation of minerals have provided opportunity for a variety of employment and livelihood options to the local people. Besides, it has also contributed towards industrial and economic development of the state. On the other hand, exploitation of rocks and minerals including coal and limestone has affected the local environment at its various stages of mining, processing and utilization.

Mining operation, undoubtedly has brought wealth and employment opportunity in the area, but simultaneously has lead to extensive environmental degradation and disruption of traditional values in the society. Environmental problems associated with mining have been felt severely because of the region's fragile ecosystems and richness of biological and cultural diversity. Large scale denudation of forest cover, scarcity of water, pollution of air, water and soil, and degradation of agricultural lands are some of the conspicuous environmental implications of coal mining in Jaintia Hills. Besides, a vast area has become physically disfigured due to haphazard dumping of overburden and mined coal, and caving in of the ground and subsistence of land.

Surface mining generates huge quantity of mine spoil or overburden (consolidated and unconsolidated materials overlying the coal seam) in the form of gravels, rocks, sand, soil etc which are dumped over a large area adjacent to the pit. The dumping of coal and overburden destroys the surrounding vegetation and leads to soil and water pollution. The indiscriminate and unscientific mining and absence of post-mining treatment and management of mined areas are making the fragile ecosystems more vulnerable to environmental degradation and leading to large scale land cover/land use changes. Continuous discharge of Acid Mine

Drainage (AMD) and toxic substances from coal mines, storage sites and exposed overburden coupled with organic pollution of anthropogenic origin, and increasing silt load are making the streams and rivers of the area highly polluted. Depletion of forest cover, pollution of air, water and soil, degradation of agricultural fields and scarcity of water and other natural resources are some major environmental issues of the coal mining areas.

5.1 Effect of Coal Mining on Water Resources

5.1.1 Major Water Bodies of Coal Mining Areas of Jaintia Hills

The major water bodies in coal mining areas of Jaintia Hills are Myntdu, Prang, Lukha and Lubha rivers which flow into the Bangladesh plain. River Myntdu originates near Jowai, the district headquarters, and flows towards Bangladesh. In the eastern side of the Jaintia Hills are the tributaries of river Kopli namely, river Mynriang, river Umiurem and river Myntang.

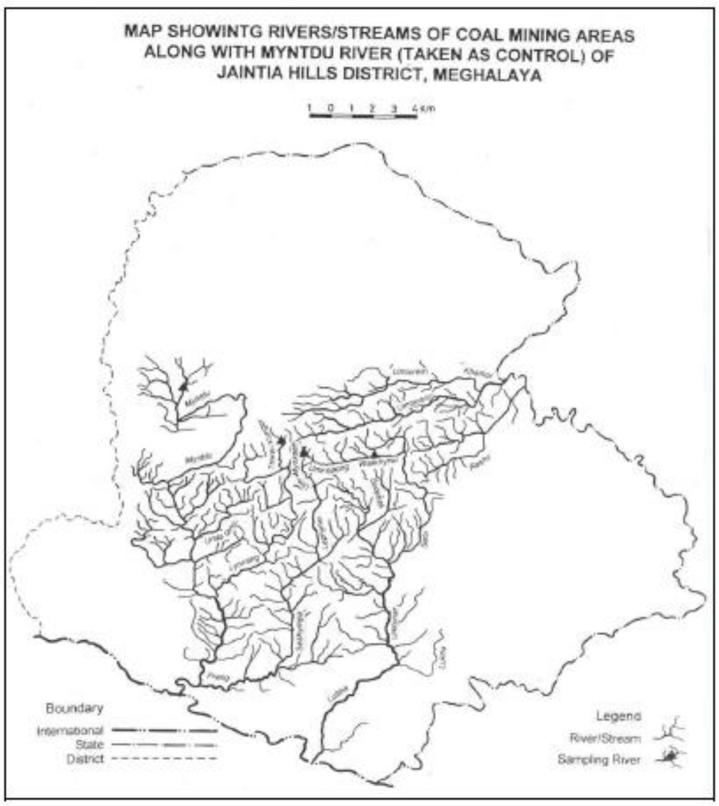

Figure 5.1: Rivers and Streams of Coal Mining Areas of Jaintia Hills

Some other rivers in coal mining are Kmai-um and Rawaka of Rymbai, Thwai Kungor of Bapung, Brilakam of Myrsiang, and Mynsar of Ioksi. A few streams namely Wah Bapung of Bapung, Umthalan of Lakadong, Mynkien of Jarain, Saitpathi of Sutnga, and Metyngka of

Rymbai are also located. The Wah Waikhyrwi (Um Roong) and Sarbang are the main rivers flowing through Sutnga area. Besides, there are a number of streams, which flow through narrow valleys. In Jarain Shkentalang area, streams flowing towards east are Um Laho, Thlumwi, and Um Pilang and towards south Umladkhur. A map showing major rivers and streams in Jaintia Hills is presented in Figure 5.1.

5.1.2 Effect of Coal Mining on Water Quality

Literature survey coupled with field visits revealed that a large number of rivers and streams drain the undulating landscape of the Jaintia Hills. Most of these rivers and streams flow towards south-east into the flood plains of Bangladesh. However, a few also flow towards northern side into the Brahmaputra valley. The major rivers and streams in Jaintia Hills are Myntdu, Prang, Lukha and Lubha rivers. Some other rivers in coal mining are Kmai-um and Rawaka of Rymbai, Thwai Kungor of Bapung, Brilakam of Myrsiang, and Mynsar of looksi.

The water bodies of the area are the greatest victims of the coal mining. The stream and rivers are badly affected by contamination of Acid Mines Drainage (AMD) originating from mines and spoils, leaching of heavy metals, organic enrichment and silting by coal and sand particles. Pollution of the water is evident by the colour of the water which in most of the rivers and streams in the mining area varies from brownish to reddish orange. Low pH (between 3-4), high conductivity, high concentration of sulphates, iron and toxic heavy metals, low dissolved oxygen (DO) and high BOD are some of the physico-chemical and biological parameters which characterize the degradation of water quality. The average values of physico-chemical parameters of water of some streams of the coal mining area in Jaintia Hills are summarized in Tables 5.1 and 5.2.

Table 5.1: Average values of physico-chemical parameters of water of some streams of coal mining area of Jaintia Hills

Rivers/Streams	Surrounding Area	Colour of water	pH	DO (mg/L)	Sulphate content (mg/L)	Conductivity (mMHOS)	Remarks
Waikhyrwi, Sutnga	Coal mining area	Brownish	**3.96**	5.94	78.69	DNA	Polluted
Rawaka, (Rymbai)	Coal mining area	Reddish brown	**2.31**	4.24	166.5	1.35	Highly polluted
Kmai-um, (Rymbai)	Coal mining area	Reddish brown	**2.66**	5.84	144.0	0.74	Highly polluted
Metyngka, (Rymbai)	Coal mining area	Reddish brown	**2.42**	4.24	168.0	2.70	Highly polluted
Um-Mynkseh, Ladrymbai	Coal mining area	Brownish orange	**3.52**	5.04	118.7	0.67	Polluted
Thwai-Kungor, Bapung	Coal mining area	Brownish	**4.01**	5.68	82.87	0.18	Polluted
Umkyrpon, Khliehriat	Coal mining area	Light orange	**3.67**	4.4	161.3	0.37	Polluted
Myntdu, Jowai	Away from Coal mining area	Bluish	**6.67**	10.2	3.66	0.10	Clean

DNA-Data Not Available.

Table 5.2: Average values of some water quality parameters of streams of coal mining areas of Jaintia Hills, Meghalaya

Sl. No.	Sampling & Location	T (^{0}C)	TU (NTU)	pH	EC (µS)	SO_4 (mg/l)	TDS (mg/Ll	TH Mg/l)
1	Molishah Stream (Shanpung) (Control)	19.08	4.87	**6.67**	30.50	7.41	79.67	19.03
2	Yalip Stream	19.12	1.74	**6.67**	31.33	2.67	72.33	23.94
3	Savanong Stream	18.77	2.61	**6.67**	36.67	5.80	79.89	19.69
4	Umpai River (Rymbai)	16.53	1.1	**2.9**	1314.33	151.49	931.0	134.72
5	Mynkseh River (Lad Rymbai)	15.76	0.69	**3.2**	562.67	113.13	397.0	131.04
6	Khyrwi River (Sutnga)	16.93	1.39	**2.9**	1113.0	161.12	790.0	140.25
7	Sarbang Stream (Sutnga)	15.33	2.47	**3.8**	230.67	81.82	263.66	137.43
8	Kopili River (Running Water)	20.46	0.73	**5.7**	79.33	69.83	204.67	112.22

The conducted field survey and laboratory analysis of water samples revealed that the water bodies in the coal mining areas are the greatest victims of the coal mining. The water bodies are badly affected by contamination of Acid Mines Drainage (AMD) originating from mines and spoils, leaching of heavy metals, organic enrichment and silting by coal and sand particles. Pollution of the water is evidenced by the colour of the water which in most of the rivers and streams in the mining area varies from brownish to reddish orange. Low pH (between 2-3), high conductivity, high concentration of sulphates, iron and toxic heavy metals, low dissolved oxygen (DO) and high BOD are some of the physico-chemical and biological parameters which characterize the degradation of water quality. Observations on physico-chemical and biological characteristics of water are discussed below.

Colour: The colour of the water in mining area generally varies from brownish to reddish orange. Siltation of coal particles, sand, soil, etc., and contamination of AMD and formation of iron hydroxide are some of the major causes of change in water colour. Formation of iron hydroxides [(Fe (OH)3] is mainly responsible for orange or red colour of water in the mining areas. Iron hydroxide is a yellowish insolube material commonly formed in water bodies of the coalfields. It is this material that stains streams and responsible for red to orange color of water. When elevated levels of iron are introduced into natural waters, the iron is oxidized and hydrolyzed, thereby forming precipitate of iron hydroxides. On the other hand, the water colour of Myntdu river which has been considered as control being located away from the mining area has been found clear with bluish tint.

pH: Data of average values of physico-chemical parameters of water of streams of Jaintia Hills show that pH value of most streams are in highly acidic range. The pH values of water was found as low as 2.31, 2.42, 2.66, 2.9 etc. The pH of water between 2 and 3 is considered highly acidic. It shows that most of the streams in coal mining areas of Jaintia Hills have become highly acidic. The pH of streams and rivers varies between 2.31 to 4.01. However, pH of the Myntdu river (unaffected by coal mining at upstream near its origin) was found to be 6.67.

Silt and suspended solids: Solids such as fine particles of coal, sand, mud and other mineral particles were found deposited at the bottom of the water bodies. Besides, water was also found turbid and coloured due to suspended precipitates of iron hydroxides. Silt, fine sand, mud, coal dust and similar materials form a covering over the bottom and disrupt the benthic habitat. In addition they reduce the availability of oxygen and light for aquatic life.

Dissolved Oxygen: Dissolved Oxygen (DO) is essential for sustaining higher forms of life in water bodies. It is an important parameter to assess water quality. Dissolved oxygen was found to be low in water bodies of coal mining areas, the lowest being 4.24 mg/L in river Rawaka and stream Metyngka of Rymbai. However, DO in water of river Myntdu was found 10.2 mg/L.

Sulphate: The waters of the mining areas have been found containing sulphate concentration between 78 to 168 mg/L. The high concentration of sulphates is mainly due to presence of iron sulphide in coal and rocks and its reaction with water and oxygen. Water of the unpolluted rivers and streams in Meghalaya contains usually very low concentration of sulphates as found in water of river Myntdu (3.66 mg/L).

Conductivity: Conductivity is the measure of the capacity of a solution to conduct electric current. It is a rapid measure of the total dissolved solids present in ionic form. In this study, the conductivity was found highest is stream Metyngka of Rymbai with 2.7 mMHOS and least in the control river Myntdu with 0.1 mMHOs.

Siltation: Solids such as fine particles of coal, sand, mud and other mineral particles were found deposited at the bottom of the water bodies. Besides, water was also found turbid and coloured due to suspended precipitates of iron hydroxides. Silt, fine sand, mud, coal dust and similar materials may be quite disruptive in streams as they destroy the benthic habitat and reduce availability of oxygen for benthic animals.

All these parameters characterize the degradation of water quality, and make the ambient unfit for supporting life. As a result, there is a drastic depletion of aquatic life, particularly of aquatic animals. The polluted water is also responsible for degradation of agricultural fields leading to low crop yield. Due to percolation of surface water in to the mine pits, smaller streams of the area, which served as life lines for the people are disappearing resulting into acute shortage of drinking and irrigation water.

5.1.3 Effect on Water Quantity

In addition to water pollution, the entire coal mining area of the Jaintia Hills has become full of mine pits and caves. These open, unfilled pits are the places where surface water percolates and disappear into the ground and reaches to lower areas. As a result, smaller streams and rivers of the area, which served as life lines for the people, are either completely disappearing from the face of the earth or becoming seasonal. Consequently, the area is facing acute shortage of clean drinking and irrigation water. Besides, a vast area has become physically disfigured due to haphazard dumping of overburden and mined coal, and caving in of the ground and subsistence of land.

5.1.4 Impact of Water Pollution on Aquatic Life

Low pH, low Dissolved Oxygen (DO), higher sulphate content and turbidity in water of coal mining areas are affecting the aquatic life. Study on benthic macro-invertebrates revealed presence of only a few tolerant species namely *Chironomus* larvae (Diptera), dragonfly larvae (Odonata) and water bugs (Hemiptera) in rivers and streams of the area. Analysis further revealed lower abundance and species diversity of macro-invertebrates. The presence of only a few tolerant species of benthic macro-invertebrates and the absence of most of the aquatic organisms particularly the sensitive species are most likely due to acidic water contaminated with AMD. Further, most of the river of the mining area lack commonly found aquatic organisms such as fish, frog and crustacean. On the other hand, studies done on river Myntdu, which is away from the coal mining area revealed relatively higher abundance and species diversity of macro-invertebrates. The species present in the river include many sensitive species such as stonefly nymph (Plecoptera), mayfly nymph (Ephemeroptera), caddisfly (Tricoptera) along with some tolerant species.

The primary cause of degradation of water quality and the declining trend of biodiversity in the water bodies of the mining area is attributed mainly to the AMD, which makes water highly acidic, turbid and rich in iron, sulphate and heavy metal concentration. Low pH is directly injurious to many freshwater animals and has diverse biological effects including changes in abundance, biomass and diversity of invertebrates. Higher concentration of heavy metal in water impairs with the normal physiological functioning of the aquatic organisms, and leads to toxicity. The effects of AMD are the result of a combination of factors which are devastating to stream ecosystem by eliminating stream macro-invertebrates, fish community, and plant species. Water bodies which are not affected by acid mine drainage support high diversity of aquatic insects belonging to orders of Ephemeroptera (Mayflies), Plecoptera (Stoneflies) and Trecoptera (Caddisflies). Mayflies are one of the most sensitive group of aquatic insect to low pH. Acid mine drainage causes a reduction in the abundance and diversity of benthic macro-invertebrates. Sensitive species are eliminated even in moderately polluted water bodies. In severely polluted condition, tolerant organisms like earthworms (Tubificidae) midge larvae (chironomidae) etc dominate and are present in abundance. Data on occurrence of macro-invertebrates and fish, frog etc. in some rivers and streams of Jaintia Hills affected by coal mining are presented in Table 5.3.

Table 5.3: Occurrence of macro-invertebrates and fish, frog etc. in rivers and streams of Jaintia Hills

Benthic macro invertebrates	Rivers/Streams							
	Myntdu (Control)	Waikhyrwi (Sutnga)	Rawaka (Rymbai)	Kmai-Um (Rymbai)	Metyngka (Rymbai)	Um-Mynkseh (Lad Rymbai)	Thwai Kongor (Bapung)	Um Krypong (Khliehriat)
Plecoptera (Stonyefly nymph)	P	A	A	A	A	A	A	A
Epheroptera (Mayfly nymph)	P	A	A	A	A	A	A	A
Tricoptera (Caddis fly larvae)	P	A	A	A	A	A	A	A
Odanata (Dragon fly)	P	P	A	A	A	P	A	A
Hemiptera (Water bugs)	P	P	A	A	A	P	A	A
Diptera (Chironomus larvae)	P	P	A	A	A	P	A	A
Crustacea	P	A	A	A	A	A	A	A
Other aquatic organisms (Fishes, Frogs & Tadpoles)	P	A	A	A	A	A	A	A

P- Present; A-Absent.

Aquatic fauna belonging to higher animal groups like fish, from, crayfish, snail, crab etc. have totally vanished from the acidic water bodies in the coal mining area of Jaintia hills due to acidic nature of water and absence of macro invertebrates which serve as food for fishes, crabs etc. Fishes, in natural habitat often depend for their food on small aquatic organisms including macroinvertebrates. As a consequence of depletion of aquatic invertebrates, the fishes do not get adequate supply of food and suffer indirectly from AMD contamination. AMD also has direct effect on fish by causing various physiological disturbances. The primary cause of fish death in acid waters is loss of sodium ions from the blood. Less availability of oxygen to the cells and tissues leads to anoxia and death as acid water increases the permeability of fish gills to water, adversely affecting the gill function (Brown and Sadler, 1989). Ionic imbalance in fish may begin at pH of 5.5 or higher, depending on the tolerance of the species. Severe anoxia occurs below pH 4.2 (Potts and McWilliams, 1989). Low pH that is not directly lethal may adversely affect fish growth rates and reproduction (Kimmel, 1983). It has been found that fish species are severely impacted below the pH 5.5. Water pH below 4.5 in most of the rivers in Jaintia Hills is most likely responsible for complete elimination of fish from the natural waters of the area.

Low pH, low DO, higher sulphate content and turbidity in water of coal mining areas are affecting the aquatic life. Study on benthic macroinvertebrates revealed presence of only a few tolerant species namely *Chironomus* larvae (Diptera), dragonfly larvae (Odonata) and water bugs (Hemiptera) in rivers and streams of the area. Analysis further revealed lower abundance and species diversity of macroinvertebrates. The presence of only a few tolerant species of benthic macroinvertebrates and the absence of most of the aquatic organisms particularly the sensitive species are most likely due to acidic water contaminated with AMD. Further, most of the rivers of the mining area lack commonly found aquatic organisms such as fish, frog and crustacean. On the other hand, studies done on river Myntdu, which is away from the coal mining area revealed relatively higher abundance and species diversity of macroinvertebrates. The species present in the river include many sensitive species such as stonefly nymph (Plecoptera), mayfly nymph (Ephemeroptera), caddisfly (Tricoptera) along with tolerant species listed above.

Most freshwater lakes, streams, and ponds have a natural pH in the range of 6 to 8. Acid deposition has many harmful ecological effects when the pH of aquatic systems falls below 6 and especially below 5. Fishes in such conditions are most affected. Fish may temporarily swim through a non-lethal impacted area or away from a discharge of intermittent duration. However, if acidity continues for a long time, then fishes and other aquatic animals are affected severely.

Some of these effects of increased acidity on aquatic ecosystems are as follows:

- As the pH approaches 5, non-desirable species of plankton and mosses may begin to invade, and populations of fish disappear.
- Below a pH of 5, fish populations begin to disappear, the bottom is covered with decaying material.
- Below a pH of 4.5, the water is essentially devoid of fish.
- Aluminium ions (Al^{3+}) and other metal ions attached to minerals in nearby soil can be released into lakes, where they can kill many kinds of fish by stimulating excessive mucus formation. This asphyxiates the fish by clogging their gills. It can also cause chronic stress that may not kill individual fish, but leads to lower body weight and smaller size and makes fish less able to compete for food and habitat.
- The most serious chronic effect of increased acidity in surface waters appears to be interference with the fish reproductive cycle. Calcium levels in the female fish may be lowered to the point where they cannot produce eggs or the eggs fail to pass from the ovaries or if fertilized, the eggs and/or larvae develop abnormally.

Aquatic communities of unaffected rivers and streams comprise of phytoplanktons, periphyton, macrophytes, zooplanktons, invertebrates and vertebrate species which play important role in normal functioning of the aquatic ecosystem. Any physical, chemical or biological change in water bodies affects one or all species and disturbs the normal functioning of the aquatic ecosystem. The benthic (bottom-dwelling) communities of rivers and streams consist of those organisms which grow in, on, or otherwise in association with various bottom substrates. Benthic macroinvertebrates are often used as indicators of water quality because of their limited mobility, relatively long residence times, and varying degrees of sensitivity to pollutants.

Unaffected streams generally have a variety of species with representatives of almost all insect orders, including a high diversity of insects classed in the taxonomic orders of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) commonly referred to as EPT taxa. Like many other potential pollutants, mine drainage causes a reduction in the diversity and total numbers, or abundance, of macroinvertebrates and changes in community structure. Water bodies affected by AMD possess a lower percentage of EPT taxa. Moderate AMD contamination eliminates the more sensitive species (Weed and Rutschky, 1971) whereas severely contaminated conditions are characterized by dominance of certain taxonomic representatives of pollution-tolerant organisms, such as aquatic worms (Tubificidae), midge larvae (Chironomidae), alderfly larvae (*Sialis*), fishfly larvae (*Nigronia*), crane fly larvae (*Tipula*), caddis fly larvae (*Ptilostomis*), and non-benthic insects like predaceous diving beetles (Dytiscidae) and water boatmen (Corixidae) etc. (Rosemond et al., 1992). While these tolerant organisms may also be present in unpolluted streams, they dominate in impacted stream sections. Mayflies are generally sensitive to acid mine drainage, however some stoneflies and caddis flies are tolerant of dilute acid mine drainage.

Fish, in natural habitat often depend for their food on small aquatic organisms including macroinvertebrates. As a consequence of depletion of aquatic invertebrates, the fishes do not get adequate supply of food and suffer indirectly from AMD contamination. AMD also has direct effect on fish by causing various physiological disturbances. The primary cause of fish death in acid waters is loss of sodium ions from the blood. Less availability of oxygen to the cells and tissues leads to anoxia and death as acid water increases the permeability of fish gills to water, adversely affecting the gill function (Brown and Sadler, 1989). Ionic imbalance in fish may begin at pH of 5.5 or higher, depending on the tolerance of the species. Severe anoxia occurs below pH 4.2 (Potts and McWilliams, 1989). Low pH that is not directly lethal may adversely affect fish growth rates and reproduction (Kimmel, 1983). It has been found that fish species are severely impacted below the pH 5.5. Water pH below 4.5 in most of the rivers in Jaintia Hills is most likely responsible for complete elimination of fish from the natural waters of the area.

5.1.5 Main Cause of Deterioration of Water Quality

Major causes of deterioration of water quality evidenced by above observations are AMD discharge, silting of bottom and organic enrichment. The AMD formation in coal mines and at the storage sites is a major sources of water pollution.

Acid Mine Drainage: Acid Mine Drainage (AMD) is the main source of water pollution in the coal mining areas. It is formed by a series of complex geochemical and microbial reactions that occur when water comes in contact with pyrite (iron sulfide) found in coal and exposed rocks of overburded. Iron sulfide in presence of oxygen, water and bacteria forms sulphuric acid, is referred to as AMD. The formation of AMD is summarized below with the help of a generalized chemical reaction (Johnson & Bradshaw, 1978):

$4\ FeS_2 + 15\ O_2 + 14\ H_2O = 4\ Fe\ (OH)_3 + 8\ H_2SO_4$

Pyrite + Oxygen + Water = “Yellow precipitate” + Sulfuric Acid

In the process, iron hydroxide, a yellowish orange precipitate is also formed. The precipitate of iron hydroxide together with other contaminants causes turbidity and changes in colour of the water which reduces the penetration of light and affects the aquatic life. Extremely low pH condition in the water accelerates weathering and dissolution of silicate and other rock minerals, thereby causing the release of other elements such as aluminum, manganese, copper, cadmium etc. into the water. Hence, water contaminated with AMD is often coloured and turbid with suspended solids, highly acidic (low pH), and contain high concentration of dissolved metals and other elements.

Deposition of silt at the bottom of the rivers and streams is another important problem in coal mining areas. Solids such as fine particles of coal, sand, mud and other mineral particles were found deposited at the bottom of the water bodies. Besides, water was also found turbid and coloured due to suspended precipitates of iron hydroxides. Silt fine sand, mud, coal dust and similar materials may be quite disruptive in streams as they destroy the benthic habitat and reduce availability of oxygen for benthic animals. Further, the water bodies of the mining area appear to contain various types of organic matter which is evident by low Dissolved Oxygen (DO) and high Biochemical Oxygen Demand (BOD). Continuously increasing human population, lack of proper sanitation and high anthropogenic pressures are responsible for different types of organic pollution in water bodies of the area. The organic matters are oxygen demanding hence leading to low DO and high BOD levels in water.

Box 5.1. Effect of Coal Mining on Water Resources

- The water bodies of the area are the greatest victims of the coal mining.
- The stream and rivers are badly affected by contamination of Acid Mine Drainage (AMD) originating from mines and spoils, leaching of heavy metals, organic enrichment and silting by coal and sand particles.
- Pollution of the water is evident by the colour of the water which in most of the rivers and streams in the mining area varies from brownish to reddish orange.
- Low pH (between 3-4), high conductivity, high concentration of sulphates, iron and toxic heavy metals, low dissolved oxygen (DO) and high BOD are some of the physico-chemical and biological parameters which characterize the degradation of water quality.
- Water resource of Jaintia Hills is also affected in terms of its quantity. These open, unfilled pits are the places where surface water percolates and disappear into the ground and reaches to lower areas. As a result, smaller streams and rivers of the area, which served as life lines for the people, are either completely disappearing from the face of the earth or becoming seasonal. Consequently, the area is facing acute shortage of clean drinking and irrigation waters in Jaintia Hills.

5.2 Impact of coal mining on soil and agriculture

Study on the effect of acid mine drainage on effect on paddy soil and productivity of rice was conducted by Choudhury et al., 2017. The soil of the region is naturally little acidic, and the soil in the paddy fields unaffected by mining similarly acidic with an average pH between 4.30 - 5.8. Coal mining, with its discharge of acid drainage and release of sulphur from minerals in the overburden has decreased the soil pH by 0.51 units to 3.79 in the soil currently affected by coal mining. Closely related to these changes are those of exchangeable Al^{3+}. Mining appears to have increased the concentration of Al^{3+} nearly 2 fold and increased its saturation of the exchange complex from 34.1% to 44.9%. The concentrations of the exchangeable Ca^{2+} and Mg^{2+} have been affected in a contrary sense where there was a 35% decrease in the concentrations of both cations. The soil affected by mining has a larger proportion of sand and correspondingly less clay than the original soil. This extra sand is presumably from the overburden. Soil aggregation was also significantly weaker in the soil affected by mining; the mean weight diameter was less than half of the control soil. The values of various soil quality parameters of coal mining affected and unaffected soils are presented in Table 5.4.

Table 5.4: Average values of various soil quality parameters (Choudhury et al., 2017)

Sl no.	**Parameters**	**Unaffected**	**CF**	**RM**
1	pH	4.3	3.79	3.96
2	Exch. Al_3+/cmol (P+) kg−1	1.64	3.11	2.13
3	Exch. Ca^{2+} + Mg^{2+}/cmol (P+) kg−1	2.82	1.82	2.13
4	Al_3+ saturation %	34.1	44.9	41.8
5	Organic carbon %	1.50	3.60	3.01
6	Mean weight diameter/mm	2.82	1.15	1.63
7	Available N/kg ha-1	261.3	306.6	305.1
8	Available P/kg ha−1	24.3	16.9	18.9
9	Available K/kg ha−1	210.2	77.2	132.6
10	Available S/kg ha−1	41.1	170.8	43.0
11	DTPA Fe/mg kg−1	84.7	260.0	200.7
12	DTPA Mn/mg kg−1	7.24	13.51	8.94
13	DTPA Cu/mg kg−1	0.4	0.7	0.69
14	DTPA Zn/mg kg−1	0.54	0.19	0.33

RM: Recovering from mining; CF: Currently affected by mining

The mine affected soil contained much more organic carbon 3.6% which can be attributed to the overburden. It was accompanied by a greater availability of nitrogen (N). The mine affected paddy soil contained 31% less available P and 63% less available K. Contamination from mining increased the available sulphur in soils by 4 times i.e. 170.8 kg ha^{-1}than the unaffected soil. The concentrations of the heavy metals Fe, Mn, and Cu extracted by DTPA were substantially greater in the mine-affected soil than in the reference and exceeded by far critical limits for the metals extracted by DTPA. In contrast, much less zinc was available in the mine-affected soil than in the reference. Further, contamination of heavy metals like Fe, Mn, and Cu, resulted in a marked diminution in the concentration of Zn relatively 64% less than in the unaffected soil.

Contamination has resulted deficiency of nutrients affecting the plant growth and productivity. Excess of available S from acid drainage exceeded the critical threshold limits by several-fold, and this effect is almost certainly the cause of the negative influence of S. Seepage and influx of acids from mining in paddy fields further acidified the already acidic soils (pH 4.4) of Jaintia Hills. Mining resulted in toxic concentration of exchangeable aluminium (Al^{3+}) and enhanced saturation of the exchange complex by Al^{3+}. It also led to large, toxic concentrations of s and heavy metal Fe, and large concentration of other heavy metals, Mn and Cu. These too can be attributed to the continuous influx of mineral contaminants (iron sulfides, oxy-hydroxide and oxyhydroxy-sulfates, and trace elements) into the fields.

The Tertiary coal deposits of Jaintia Hills are rich in sulfur (2 to12%) and the dominant mineral phases are biogenic pyrites (rich in Fe and S), marcasite, jarosite, siderite, etc. As a result, drainage from the mineral waste is strongly acidic(pH: 2.0–3.0), and also very rich in S, Fe, Al, Mn, and SO_4^{2-}.Oxidation of pyrites (at pH<4.0) releases oxidized Fe (Fe^{3+}) and sulfate (SO_4^{2-}) compounds This might have resulted in the large (toxic) concentration of Al^{3+} and its substantial saturation of the exchange complex, and the accumulation of Fe, Mn and S in the soil. The significantly larger (>57%) content organic C in mine-affected soil may be attributed to the presence of coal dust and carbonaceous shell in the overburden materials and their deposition through influx in contaminated paddy field. The growth of shoots and roots was significantly ($p < 0.05$) less in mine-affected soils. Low pH results in excess Fe (toxic) that causes deficiencies of several nutrient elements, especially P, K, Ca, Mg, and Zn in low land acidic rice soil and results in yield reduction of rice from 12% to complete failure. In mine-affected soils, abiotic stresses (toxicity in Al^{3+}, Fe and S plus P deficiency) induced by acidity reduced both the dry matter. significantly ($p<0.05$) greater concentrations of extractable heavy metals in shoots of rice grown in pots with mine affected soils: Fe (62 mg kg^{-1}) and Mn (130 mg kg^{-1}) have discovered that excessive aluminum, very low pH and concentrations of S, Fe and Mn exceeding thresholds in mine-contaminated soils resulted in phyto-toxicity and accumulation of toxic metals (Fe, Cu, Zn, Mn, Pb, Cd, Hg, etc.) in plants, including rice; root growth was inhibited, uptake of phosphorus was diminished, and as a result crop performance severely declined.

These conditions often lead to accumulation of metals in human organs through the food chain and in turn to severe disease. Study showed that when mining ceases the soil begins to recover its productivity. After 4 years the pH had risen somewhat, the concentration of $Al^{3}+$

had diminished, and the availability of the macro-nutrients, in particular K, and the micro-nutrient Zn had increased. The heavy metals Fe, Mn and Cu had declined in concentration. Only S had returned to its pre-mining status as judged by the measurements on the unaffected soil, overburden from the coalmines in the Jaintia Hills dumped on to paddy land and the acid drainage from it have acidified the soil, contaminated it with heavy metals and left the soil depleted in potassium and zinc. As a result, the soil thus affected is much less productive for paddy than uncontaminated land.

5.3 General environmental implications of coal mining

Mining operation, undoubtedly has brought wealth and employment opportunity in the area, but simultaneously has lead to extensive environmental degradation and erosion of traditional values in the society. Environmental problems associated with mining have been felt severely because of the region's fragile ecosystems and richness of biological and cultural diversity. The indiscriminate and unscientific mining and absence of post mining treatment and management of mined areas are making the fragile ecosystems more vulnerable to environmental degradation and leading to large scale land cover/land use changes. The current modus operandi of surface mining in the area generates huge quantity of mine spoil or overburden (consolidated and unconsolidated materials overlying the coal seam) in the form of gravels, rocks, sand, soil, etc., which are dumped over a large area adjacent to the mine pits. The dumping of overburden and coal destroys the surrounding vegetation and leads to severe soil and water pollution. Large scale denudation of forest cover, scarcity of water, pollution of air, water and soil, and degradation of agricultural lands are some of the conspicuous environmental implications of coal mining in Jaintia Hills.

Further, entire coal mining area of the Jaintia hills has become full of mine pits and caves.

These open, unfilled pits are the places where surface water percolates and disappears. As a result, smaller streams and rivers of the area, which served as life lines for the people, are either completely disappearing from the face of the earth or becoming seasonal. Consequently, the area is facing acute shortage of clean drinking and irrigation water. Besides, a vast area has become physically disfigured due to haphazard dumping of overburden and mined coal, and caving in of the ground and subsistence of land.

5.4 Remediation of the problem

Under prevailing grave conditions of general environment and water quality and aquatic life in rivers and streams of Jaintia Hills, there is an urgent need for initiating activities for ecorestoration of the affected areas. Here, we describe some measures to mitigate the environmental problems of the area including the improvement of water quality. Filling of mine pits, channeling of acidic seepage for checking AMD contamination of water bodies and crop fields, extensive afforestation, neutralization of acidity, conservation of topsoil etc. coupled with scientific management of mining operation are some of the measures which can be helpful in ameliorating the environmental problems of the area.

5.4.1 Filling of abandoned mines

Abandoned mines are continuous source of AMD, as the exposed rocks come in contact with water and air, and generate acidic seepage for long time to come. Abandoned unfilled mines cause subsistence of land mass and development of cracks that promote percolation of surface water, erosion of topsoil and generation of AMD. Hence, it is very important to fill the mines with the same overburden material that was removed during the process of mining. Additional rocks, sand and soil can also be used to fill the mines.

5.4.2 Extensive afforestation and revegetation of the mined areas

Establishing vegetation on coal mined land is an important step in the process of ecorestoration. Vegetation helps in stabilizing the soil surface from erosion and controlling siltation. From the viewpoint of preventing acid mine drainage, vegetation is beneficial for reducing the amount of water and atmospheric oxygen entering the mine overburden. Some plants, particularly undergrowth helps in removal of dissolved metals and other toxic components from the water and soil. Hence, extensive afforestation of the mined areas with local and tolerant plant species will be of great help in ecorestoration of the degraded ecosystems.

5.4.3 Conservation of topsoil

Soil is essential for plant growth and agricultural productivity. Once lost, it takes decades in formation and regeneration. Hence, conservation of top soil is very important in the process of ecorestoration. Removal of topsoil prior to mining and its replacement as the final cover following coal mining is most beneficial method for assuring quick establishment of vegetation and ecorestoration. In addition to the benefits of topsoiling for improving vegetation and restoring pre-mining soil productivity, topsoil also helps in retention of water for plant growth. Further, topsoil limits the infiltration of water into the ground. It has been found that a final cover of topsoil on a mine backfill significantly reduces the infiltration rate of water. Limited infiltration of water means less production of AMD.

5.4.4 Management of AMD and Surface Water

Proper management of AMD and surface water in mining areas can be of great use in mitigation of water pollution and related environmental problems. Channeling of AMD and its prevention from contamination of agricultural fields and water resources can save agricultural land and water bodies from degradation. Use of proper water management techniques to prevent AMD on mining sites can also control erosion and sedimentation, and surface water infiltration.

Water, a precious natural resource is vital for life of all organisms on the earth. Clean water is critical to the health, economic and social well-being, and quality of life. Any undesirable change in water quality affects not only the human beings and their activities but also a variety of flora and fauna of the area. As a result, the same life sustaining water turns into a life threatening substance that affects living organisms at different levels.

As a result, the rivers and streams which had supported extremely rich biodiversity and traditional agriculture, and were sources of potable and irrigation water in the area, now carry polluted water. The level of pollution has reached to the extent that water has become unfit for human consumption and irrigation, and toxic to plants and animals. Consequently, the same rivers and streams that supported human life and activities, and rich biodiversity including many species of fish, amphibians, aquatic insects etc. have now lost their life sustaining role and become nearly devoid of aquatic life. Under prevailing grave conditions of water quality and aquatic life in rivers and streams of Jaintia Hills, there is an urgent need for initiating activities for ecorestoration of the affected areas. Filling of abandoned mines, extensive afforestation, neutralization of acidic seepage, conservation of top soil, scientific management of AMD and water resources etc. will go a long way in restoration of the lost environmental glory of the area.

5.4.5 Neutralization of acidity

The above described preventive measures can help in controlling the AMD formation and reducing the future pollution load. However, preventive measures cannot deal with acidic mine drainage already accumulated in the mining area because prevention techniques mainly focus on inhibiting AMD formation. However the remediation techniques focus on the treatment of already produced AMD before its discharge into water bodies and agricultural fields.

The conventionally used treatment technologies can be divided into two broad categories: active treatment and passive treatment. The active treatment methods are costly and require labour intensive maintenance. Hence, active treatment methods are used to get rid of acidity in emergency situations. On the other hand, the “passive treatment” methods rely on biological, geochemical, and gravitational processes. Passive treatment does not require constant care or the chemical reagents that characterize “active” AMD treatment. Thus, the passive treatment technologies are relatively less expensive, eco-friendly and require less maintenance. Due to these advantages the passive treatment technologies are widely used all over the world.

5.4.5.1 Passive Treatment Technologies

Passive treatment systems for acid drainage are intended to improve the quality of waters that pass through them. A critical step in designing passive treatment is to characterize the waters to be treated. This can be done by measuring the discharge or flow of those waters and knowing the values of various water quality parameters over an extended period to determine seasonal variations in quantity and quality. Site characteristics, especially land terrain and gradient, also influence passive treatment system selection and design. Further, different passive treatment methods can be grouped into two- Aerobic/Oxic and Anaerobic treatments.

Some conventional passive treatment technologies are open limestone channels, anoxic limestone drains, limestone leach beds and slag leach beds, constructed wetlands and phytoremediation. Some of these technologies, separately or in combination can be effective in treatment of AMD contaminated water sources in coal mining areas of Meghalaya. However, before choosing and applying these treatment technologies intensive research is needed to develop an efficient and cost-effective AMD treatment method for the coal mining affected areas of Meghalaya, particularly in Jaintia Hills as all treatment technologies discussed here may not be suitable, effective and economically viable in remediation. Some widely used methods of passive treatment (both Aerobic/Oxic and Anaerobic) are described below.

Open Limestone Channels

Treatment of AMD contaminated acidic water by Open Limestone Channels (OLCs) is the simplest form of passive treatment. These are open channels that contain a coarse aggregate of limestone, and the water is diverted through it. A typical OLC may have 0.3 meters to 1 meter of limestone at the bottom. Various sized limestone are placed along the bottom and sides of the channel, and the AMD flows through these limestone. OLC introduces alkalinity to acid mine water and is supposed to raise the pH of the acid water to 6–8. For optimum performance, the OLC is designed considering the pH level of water and its nature. Factors like channel dimensions (especially length) and channel slope are given importance in design and construction of an OLC system. The drain length should be sufficiently long, so that mine drainage water gets enough contact time with limestone for proper neutralization. If the slope is more than 10 degrees, acid mine water will pass through the limestone aggregate too fast. Hence, there will not be adequate neutralization. In too low slope drains heavy metal precipitates (armouring or coating of the limestone) will occur around limestone and within its void spaces and decreases the neutralizing capacity. For efficient performance, channel gradient should be more than 20%. The OLC neutralizes and removes the heavy and toxic metals from the acidic water. For better results, OLC can be used with other passive treatment technologies[1].

Coating of limestone with precipitates of iron and growth of algae may take place after certain period of treatment. The coated or armoured limestone is less effective in neutralization and thus needs cleaning or replacement with new materials for treatment effectiveness. Cleaning can be done by washing with jet of water and other methods for refreshing the surface for treatment effectiveness.

Anoxic Limestone Drains (ALD)

An anoxic limestone drain (ALD) is below ground limestone aggregate beds (covered in plastic or impervious liner, and then capped with clay or compacted soil) along gently graded slopes through which an unaerated AMD contaminated water flows by gravity. With these capping of clay or organic matter, it is ensured that minimum or no air enters into the drain, the exclusion of oxygen with AMD prevents oxidation of metals and clogging of the system. The trenches can be designed considering the volume of water to be treated and its physico-chemical properties. This system requires 14-15 hours retention time. The objective with ALD is to add alkali to AMD while maintaining the iron in its reduced form to avoid the oxidation of ferrous iron and precipitation of ferric hydroxide on the limestone. The prime function of an ALD is to provide bicarbonate alkalinity via limestone dissolution and to raise the pH of AMD to 6–8 hence converting net acid water into net alkaline water.

The ALD's are suitable for the treatment of AMD from coal mines because coal mines are generally associated with reduced water, in which iron precipitation is minimised. As long as the reduced state of influent AMD is maintained in the ALD, the rate of armouring of limestone with iron precipitates and associated blocking of ALD flow pathways should be minimal. Anoxic Limestone Drains provide a relatively inexpensive form of alkalinity addition. Maintenance costs for ALD's are very low, and are associated with periodic inspection of the ALD and upkeep of the vegetation cover. However, maintenance of the limestone layer can prove difficult due to the buried trench design of the system.

Aerobic wetlands

An aerobic wetland has a large surface area shallow pond (lined or unlined) filled with organic matter, for example, compost and contain a layer of limestone gravel on the bottom with the nearly horizontal flow of AMD contaminated water through it. The pond may be planted with wetland species which prevent channeling (e.g., regulate water flow) and also filter and stabilize the accumulating ferric precipitates. It is designed for natural oxidation and precipitation of metals like iron, manganese, and other metals from the water. Wetland plants remove heavy and toxic metals from acidic water by adsorption. The metal adsorption capacity of wetlands depends on many factors like concentrations of dissolved metals, dissolved oxygen (DO), air, pH, alkalinity of AMD, active microbial biomass and the retention time of AMD in the wetland. The size of the wetland depends on the influent load entering the wetland. Aerobic wetlands are a good option for long-term treatment in low maintenance and operational costs but these wetlands require longer detention time and huge surface area for acid mine water treatment. Aerobic wetlands are used to treat mildly acidic waters containing elevated Fe concentrations. They have limited capacity to neutralize acidity. The aerobic wetlands work better in combination with other treatment technologies like OLD, ALD etc.

Anaerobic Wetlands

Anaerobic wetland includes a bed of limestone beneath or mixed with an organic substrate, which encourages generation of alkalinity as bicarbonate (HCO_3) which effectively treats the acidic waters. The limestone is placed so that waters must move through organic substrate prior to contacting it, which allows bacteria in the organic material to remove O_2 from the percolating waters. This process helps to prevent armoring of the limestone. In anaerobic wetlands sulfate-reducing bacteria utilize the oxygen that enters the anoxic environment as a component of sulfate (SO_4^{2-}) for metabolic processing of biodegradable organics, transforming the associated S to either hydrogen sulfide gas (H_2S) or to a solid-phase sulfide. The most common form of sulfide reduction generates H_2S and bicarbonate alkalinity. Sulfate reduction is a microbial process that occurs under anoxic (low O_2) conditions when sulfates and biodegradable organics are present. When acid-soluble metals are in solution, sulfate reduction can form solid-phase metal sulfides as an alternative end product, which removes metals from solution and deposits them in the substrate.

Fig. 5.2a: Photograph of an open limestone Channel [2]

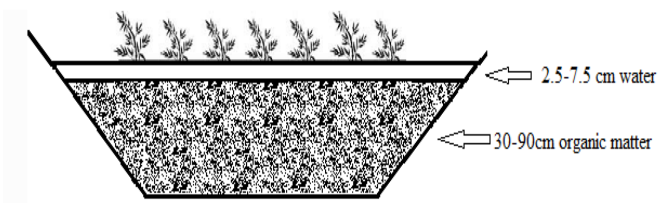

Fig. 5.2b: Typical Section of an Aerobic Wetland [3]

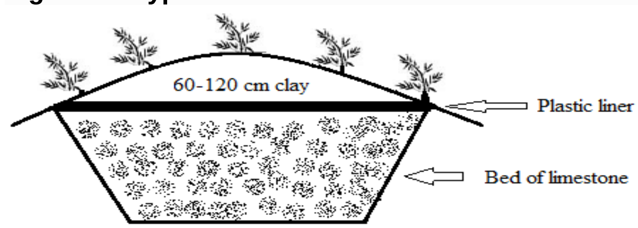

Fig 5.2c: Anoxic limestone drains [3]

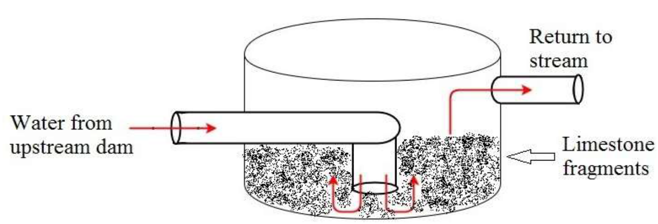

Fig. 5.2d: Schematic view of a diversion well [3]

Figures 5.2a, b, c & d: Photograph/diagrams of some passive treatment technologies used in remediation of acidic water/acid mine drainage

The other alkalinity generating process is dissolution of the limestone within or below the organic substrate: $CaCO_3 + H+ \rightarrow Ca^{2+} + HCO_3$. The bicarbonate (HCO_3^-) is a source of alkalinity, and can neutralize H^+ and/or raise pH to enhance precipitation of acid-soluble metals: $HCO_3^- + H^+ \rightarrow H_2O + CO_2$ (aq). Some of the passive treatment technologies used in remediation of acidic water/acid mine drainage are depicted in Figure 5.2a, b, c, & d.

In-Stream Limestone Sand

Limestone sand is placed directly into the streambed of high-gradient headwater streams. The sand dissolves into the water column as it spreads downstream during high stream flow periods. Dissolved limestone sand adds $CaCO_3$, which in turn results in higher pH. Where to add the limestone depends on treatment objectives and road access. Wherever the limestone is placed, the site should have sufficient flow and stream gradient to carry sand downstream. Roads, weather, and water quality dictate the timing of limestone sand addition. The frequency and timing of limestone sand addition may vary with stream conditions. The type of limestone sand added should be Grade A agricultural limestone, with high $CaCO_3$ content and of sand size (average diameter of about 0.02 inches). The amount of limestone sand added should, theoretically, be sufficient to neutralize the acid load in the stream.

Limestone Diversion Wells

Diversion wells are used to raise alkalinity and pH in streams affected by acid mine drainage. The diversion well is a concrete circular casing that resembles a large diameter, shallow well sunk into the ground next to the stream. To force water through the well, a small intake dam is constructed upstream from the well to create an elevation difference between the well and the intake of 8 feet to 13 feet. Water enters through an intake pipe at the dam and is piped downstream to the well. Water exits the pipe a few inches from the bottom of the well and flows upward, fluidizing or suspending the limestone, before it exits through an overflow pipe back into the stream. The fluidized bed of limestone dissolves and is slowly added to the stream. The suspended gravel-sized particles grind against one another improving their solubility by maintaining fresh reaction surfaces. The limestone gravel should be about 0.8 to 1.2 inches in diameter and have high calcium content. The well should be filled to about 2/3 its depth with limestone. Generally the well can hold enough limestone to last 1 to 2 weeks. Limestone diversion wells can treat streams with relatively small flows and raises pH. When necessary, more than one diversion well may be constructed on a stream system to provide adequate acid neutralization.

Vertical Flow System

Vertical flow passive-treatment systems combine the treatment mechanisms of anaerobic wetlands and ALDs in an attempt to compensate for the limitations of both. The basic elements of this system are similar to the anaerobic wetland, but a drainage system is added to force the AMD into direct contact with the alkalinity producing substrate. The three major system elements are the drainage system, a limestone layer, and an organic layer. The system is constructed within a water-tight basin, and the drainage system is constructed with a standpipe to control water depths and ensure that the organic and limestone layers remain submerged. As the AMD waters flow downward through the organic layer, the dissolved oxygen is utilized by aerobic bacteria utilizing biodegradable organic compounds. Low dissolved oxygen prevents limestone armouring. In the limestone layer, $CaCO_3$ is dissolved by the acidic, anoxic waters moving down to the drainage system, producing additional alkalinity. The final effluent is discharged into a settling pond for acid neutralization and metal precipitation prior to ultimate discharge. For treating highly acidic discharges, several vertical flow cells can be placed in sequence, separated by settling ponds.

Vertical flow systems can neutralize acidity and promote metal precipitation in difficult treatment situations. Due to the forced contact of the AMD with the limestone, acid neutralization is more rapid in vertical flow systems than in anaerobic wetlands, so vertical flow systems generally require shorter residence time and smaller surface areas. Two major limitations to the long term performance of vertical flow systems are accumulation of metal floc, primarily Fe and Al in the limestone layer, and degradation of the organic layer. This system requires good quality of limestone. To operate properly, the organic layer must be sufficiently biodegradable. It also must be permeable, so water can move through it into the limestone.

Successive Alkalinity Producing System (SAPS)

The Successive Alkalinity Producing System (SAPS) is a combination of an ALD with an anaerobic wetland/pond. The AMD flows through a pool of water, an organic substrate, and a limestone bed before discharging from the bottom. The organic substrate and the depth of water create the anaerobic conditions necessary to reduce the likelihood of metals precipitating and clogging the limestone. The SAPS should empty into an aerobic wetland and/ or settling pond for metal removal.

Box 5.2: Passive Treatment

- The passive treatment methods rely on biological, geochemical, and gravitational processes to neutralize acidity and remove metals from AMD or AMD contaminated water.
- A passive treatment system for acid mine drainage is intended to improve the quality of waters by passing it through natural materials and through natural processes. Passive treatments can be Aerobic/Oxic or Anaerobic.
- Site characteristics, rock composition and land terrain and gradient etc. influence the passive treatment.
- Some of the conventional and emerging passive treatment technologies are constructed wetlands, anaerobic sulfate-reducing bioreactors, anoxic limestone drains, open limestone channels, limestone leach beds, slag leach beds and phytoremediation.
- The passive treatments technologies are relatively less expensive, eco-friendly and require less maintenance and therefore widely used all over the world.

5.4.5.2 Active Treatment Methods

In active treatment alkaline chemicals are added to AMD or AMD contaminated water to raise the pH and precipitate metals. Six chemicals can be used to treat acidic water. Each chemical has a particular characteristic that make it more or less appropriate for a specific condition. These chemicals are chosen based on both technical and economic grounds. The technical factors include acidity levels, flow, and the types and concentrations of metals in the water. The economic factors include prices of reagents and cost of its application. One of the major advantages of the active treatment process is that it is fast and effective in removing acidity and metals. However, active treatment processes are relatively expensive as it involves recurring cost of adding chemicals and needs regular maintenance of the system.

Alkaline Chemicals Commonly Used in Active Treatment

A variety of alkaline materials can be used to treat acidic water. They are selected on case to case basis for treatment of acidic environment considering local conditions, cost of the chemical and sustainability. Some commonly used chemicals recommended for neutralization of acidic environment are discussed below.

Limestone: Limestone has been used for decades to raise pH and precipitate metals in AMD. It has the lowest material cost and is the safest and easiest to handle of the chemicals used for treatment of AMD. Unfortunately, its successful application has been limited due to its low solubility and tendency to develop an external coating, or armour, of $Fe(OH)_3$ when added to AMD. In cases where pH is low and acidic water contains relatively low metal concentrations, finely-ground limestone is dumped in streams directly to raise pH of the stream.

Hydrated Lime: Hydrated lime is a commonly-used chemical for treating AMD. It is sold as a powder that tends to be hydrophobic, and extensive mechanical mixing is required to disperse it in water. Hydrated lime is particularly useful and cost effective in large flow, high acidity situations where a lime treatment plant with a mixer/aerator is constructed to help dispense and mix the chemical with the water.

Soda Ash: Soda ash (Na_2CO_3) is generally used to treat AMD in remote areas with low flow and low amounts of acidity and metals. Selection of Na_2CO_3 for treating AMD is usually based on convenience rather than chemical cost.

Caustic Soda: Caustic soda (NaOH) is often used in remote locations (e.g., where electricity is unavailable), and in low flow, high acidity situations.

Ammonia: Ammonia (NH_3) is a gas at ambient temperatures. The compressed ammonia can be stored in liquid form which turns to the gaseous state when released. Ammonia is extremely soluble in water and reacts rapidly. It behaves as a strong base/alkali and can easily raise the pH of receiving water. Ammonia or anhydrous ammonia (NH_3 or NH_4OH) is an extremely hazardous chemical that must be handled carefully.

Processes in Active Treatment technology

The Active treatment technologies involve treating mine drainage with alkaline chemical to raise water pH, neutralize acidity and precipitate metals. After active treatment, precipitation of metal hydroxides is induced by electro-precipitation processes or by metal ion adsorption.

Thereafter, metal hydroxide solids are removed from the treated water by allowing settling and sedimentation of particles in a pond.

Active AMD Treatment Technologies are facilitated by Chemical Precipitation (Removal of metals by neutralization using a hydroxide precipitate-caustic soda treatment); In-Line Aeration (where the treatment reactions are closely monitored and accelerated in order to reduce the chemical reagent costs and reaction); Electro-precipitation (precipitation of metal hydroxides by passing electricity); Oxidation (reduced metals like Fe^{2+}, Mn^{2+} are oxidized to Fe^{3+}, Mn^{4+} by transferring oxygen into the water); Sedimentation (settling and sedimentation of metal hydroxide solids in suspension by gravity); Reverse Osmosis (Membrane separation technology to remove metal ions via micro filtration, nano filtration and reverse osmosis); and Ion Exchange (removal of ions from solution by exchange similarly charged ions attached to an immobile solid particle).

Based on above information it can be concluded that active chemical treatment can provide effective remediation of AMD, it has the disadvantages of high operating costs and problems with disposal of the bulky sludge that is produced. Active treatment can be used at small scale but large scale AMD remediation by active methods may not prove economically viable.

Box 5.3: Active Treatment

- The active treatment involves addition of various acid-neutralizing and metal-precipitating chemical agents into AMD or AMD contaminated water.
- A wide range of chemical agents such as limestone ($CaCO_3$), hydrated lime ($Ca(OH)_2$), caustic soda ($NaOH$), soda ash (Na_2CO_3), calcium oxide (CaO), anhydrous ammonia (NH_3), magnesium oxide (MgO) and magnesium hydroxide ($Mg(OH)_2$) are used during the active treatment of AMD water worldwide.
- The active treatment does not require any additional space or construction; is fast and effective in removing acidity and metals; and lower cost is involved in handling and disposal of sludge in comparison to that of passive treatment.
- However, it requires a continuous supply of chemicals, energy and manpower to operate efficiently thus it is costly. Also, some chemicals are of extremely hazardous nature and need careful handling; and the use of some chemicals (like excessive ammonia) can create problems of nitrification and denitrification in receiving water bodies.
- Due to high cost and certain other disadvantages active treatment technologies are not favoured and passive treatments are widely used all over the world.

Various carbonate minerals such as limestone, calcite, dolomite etc. are found in nature in abundance. These materials produce alkalinity thus can reduce the effect of AMD in two ways. If alkaline water comes in contact with pyrite, the acid-generating reactions may be inhibited so that little or no AMD is formed. Alternatively, once AMD has formed, its interaction with alkaline materials may neutralize the acidity and promote the removal of Fe, Al and other metals from the water. Use of such alkaline materials in scientific manner may reduce the acidity of water and save agricultural fields and water bodies to some extent.

5.5 Effect of Limestone Mining on Water Resources

As mentioned earlier extensive limestone mining is going on in Jaintia Hills region. Limestone mining in East Jaintia Hills is being carried out extensively for the production of cement. Extraction of limestone is done mainly by adopting opencast method of mining. Mining activities have deteriorated the environment of the area in terms of deforestation, biodiversity loss, water quality and availability of clean water, noise pollution, landscape disturbance, soil erosion, generation of spoils and degradation of land. Mining is known to affect water resources severely both in terms of its quantity and quality. Changes in water levels and flow, availability of potable and irrigation water, changes in sediment flow and deposition, degradation of water quality, reduction and degradation of habitat of aquatic flora and fauna and decrease in abundance and diversity of aquatic species are some of the adverse impacts of mining. A brief account of effects on limestone mining on water is given below.

5.5.1 Effect of Limestone Mining on Water Quality

Like any other mining, the mining of limestone rocks also causes alteration in the quality of surface water in terms of high content of calcium, bicarbonates, sodium and chloride salts in the water of streams and rivers receiving a significant volume of mine water generated from open cast limestone mining areas. Water quality analysis gives us an idea about the health of the water bodies. Thus water samples from three different seasons of the year were analysed to see the changes in its quality in relation to limestone mining in Jaitia Hills..

5.5.1.1 Study Area: Limestone mining in East Jaintia Hills District starts from Nongsning village to Lumshnong along the NH.44 which is at a distance of approximately 130 Km from the Shillong city (State Capital). The area has the richest limestone deposits in the state. At present, limestone mining is being carried out extensively by eight cement plant factories (companies' own quarrying sites) as well as by the private land owners of the area. The study area and sampling locations are depicted in Figure 5.3.

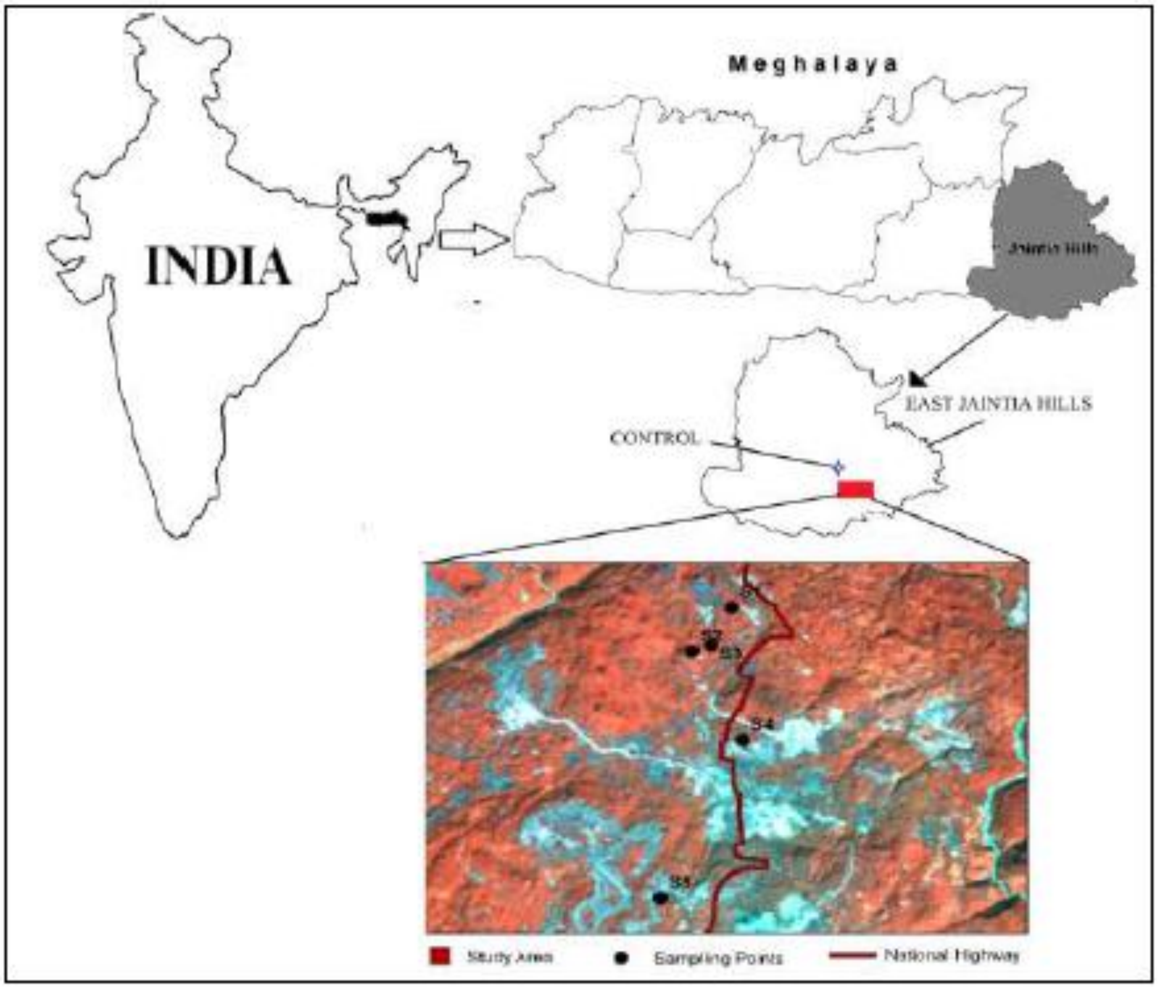

Figure 5.3: Map showing the study area (without scaling)

5.5.1.2 Sample Collection: Water samples was collected during the Pre-Monsoon (April-May) and Post-Monsoon (October- November) seasons of 2013, from five different sampling stations in the vicinity of limestone mining area and from Myntdu River Headwater as control, by Grab sampling method. Of the five sampling sites (Table-13), three sampling stations S1, S2 and S3 were near the limestone quarry sites whereas S4 and S5 were from the water bodies contaminated by the wastewater from cement industries. The latter sources are now no longer used for drinking and other domestic purposes due to their contamination by the waste from cement plant. Details of different sampling sites from where water samples was collected for the present Table 5.5.

Table 5.5: Details of different sampling sites from where water samples was collected for the present study

Details of different sampling sites from where water samples was collected for the present study

Sampling Stations	Water Bodies Local Name	Location	GPS Reading	Stations Description
Control (Co)	Myntdu	Jowai	N25°47'49.7" E92°20'93.7"	Situated at 200-300 m south of headwater. Rocky river bed. Away from mining activities and heavy anthropogenic disturbances
S1	Mih-Chariang	Nongsning	N25°24'67.7" E92°37'71.9"	Only sources of drinking water to the nearby area. At least 50 -70 m south of one quarry sites. Large volume of mine water emanating from the mining sites can be seen contaminating the sources during rainy seasons.
S2	Wah-Rkhiang	Mynkree	N25°23'56.8" E92°37'57.4"	Situated alongside the limestone quarry. Streams bed is covered with a thick sand deposition.
S3	Pom-Pa	Mynkree	N25°23'06.6" E92°37'89.2"	Situated on the side of another quarry. The streams bed and bank are rugged, deposited with stone and gravel of different size.
S4	Jynrong	Wahiajer Narpuh	N25°19'61.3" E92°39'11.3"	Situated inside the forest at least 1.5 Km south from one of the cement plant. Heavy sand deposition observed on stream bed. Once the source of water supply to the nearby locality.
S5	Umjri	Lumshnong	N25°17'97.8" E92°36'32.2"	Situated approximately 0.5 to 1 km south of another cement plant. Once the source of drinking water to the Lumshnong locality. Dull appearances of the water body.

Assessment of water quality in limestone mining areas of Meghalaya was carried out in East Jaintia Hills. Study found that both limestone mining and cement plants have negative impact on the physico-chemical characteristics of water of the area. Study found elevated levels of pH, conductivity, dissolve solids, hardness, calcium and sulphate in affected streams. The Cement plants were found contributing towards water quality degradation than the limestone mining in East Jaintia Hills, Meghalaya. Mining and processing of limestone generate overburden and limestone waste materials that are disposed off in the nearby areas pose some environmental problems, including adverse effect on water quality. The pre-monsoon, post-monsoon and winter seasons' water quality data are summarized below.

5.5.1.3 Water Quality Data during Pre-monsoon and Post monsoon Seasons

The average values of various water quality parameters of water samples collected from different locations in Jaintia Hills during Pre-monsoon and Post-monsoon seasons are presented in Table 5.6 a & b. However, the same is diagrammatically depicted in Figure 5.4.

Table 5.6a & b: Average values of various water quality parameters of water samples collected from different locations in Jaintia Hills during Pre-monsoon and Post-monsoon seasons

Pre-Monsoon season (PRM) data for different parameters of different stations from the study area

Sampling Stations / Parameters	Control (Co)	S1	S2	S3	S4	S5
Water Temp. ^{O}C	23.9 ± 0.14	21.5 ± 0.56	23.1 ± 0.07	22.5 ± 0.28	23.0 ± 0.91	22.5 ± 0.21
pH	7.0 ± 0.1	8.0 ± 0.05	8.0 ± 0.05	7.9 ± 0.05	7.3 ± 0.1	7.4 ± 0.11
EC (NTU)	22.66 ± 0.57	196 ± 4.35	129.33 ± 8.38	197 ± 5.19	443 ± 3	502 ± 5.19
TDS*	23.33 ± 5.77	76.66 ± 11.54	113.33 ± 5.77	96.66 ± 5.77	286.66 ± 20.81	386.66 ± 15.27
Alkalinity*	23 ± 1.73	110.33 ±1.52	74.66 ±0.57	99.66 ± 0.57	112 ± 1	114 ± 0
Total Hardness*	12.66 ± 1.15	126.66 ± 11.54	91.33 ± 3.05	115.33 ± 2.3	264.66 ± 4.61	299.33 ± 1.15
Calcium*	2.52 ± 0.84	43.45 ± 0.97	32.8 ± 0.84	38.12 ± 1.28	98.12 ± 2.56	104.57 ± 1.75
Magnesium*	1.54 ± 0.58	4.41 ± 3.14	2.29 ±0.25	4.89 ± 1.25	4.7 ± 2.08	9.29 ± 1.27
Dissolve Oxygen*	7.18 ± 0.11	7.98 ± 0.11	6.71 ± 0.5	6.64 ± 0.4	7.44 ± 0.2	7.78 ± 0.11
Sulphate*	56.25 ± 3.12	63.54 ± 1.8	232.29 ± 6.5	162.5 ± 3.12	814.58 ± 1.8	840.62 ± 3.12
Chloride*	7.99 ± 0.49	11.66 ± 1.52	9.33 ± 0.28	10.16 ± 0.28	11.66 ± 0.57	10.66 ± 0.57
Phosphate*	2.16 ± 0.04	2.0 ± 0.12	1.94 ± 0.12	1.67 ±0.04	2.02 ± 0.12	1.97 ± 0.08
Sodium (ppm)	1.73 ± 0.05	0.46 ± 0.05	1.83 ± 0.05	1.2 ± 0.1	1.73 ± 0.05	1.93 ± 0.05
Potassium (ppm)	1.06 ±0.05	0.1 ± 0	2.36 ± 0.05	0.8 ± 0.1	1.43 ± 0.05	3.83 ± 0.05

NB: The values of all parameters marked with asterix (*) are represented in mg/l

Post-Monsoon season (POM) data for different parameters of different stations from the study area

Sampling Stations / Parameters	Control (Co)	S1	S2	S3	S4	S5
Water Temp. ^{O}C	22.2 ± 0.42	21.9 ± 0.35	24.7 ± 0.21	23.1 ± 1.06	23.3 ± 0.42	23 ± 0.14
pH	7.7 ± 0.15	7.7 ± 0.1	8.2 ± 0.05	8.1 ± 0.05	7.2 ± 0.11	7.7 ± 0.17
EC (NTU)	27.33 ± 2.3	199 ± 3	149 ± 1.73	228.33 ± 1.15	474 ± 2	519.66 ± 2.51
TDS*	33.33 ± 5.77	106.66 ± 5.77	70 ± 4.1	140 ± 4.1	386.66 ± 11.54	433.33 ± 15.27
Alkalinity*	38 ± 3.46	124 ± 7	86.33 ± 4.04	133.66 ± 2.08	125.66 ± 2.51	127.66 ± 2.51
Total Hardness*	22.66 ± 5.03	135.33 ± 3.05	87.33 ± 5.03	148.66 ± 3.05	305.33 ± 9.45	360.66 ± 13.61
Calcium*	3.92 ± 0.48	47.65 ± 2.56	27.47 ± 3.18	48.5 ± 2.7	112.98 ± 1.75	112.42 ± 0.97
Magnesium*	3.12 ± 1.49	3.97 ± 1.82	4.55 ± 3.04	6.7 ± 1.08	5.64 ± 1.96	19.43 ± 2.73
Dissolve Oxygen*	7.85 ± 0	8.25 ± 0	7.65 ± 0.2	7.71 ± 0.23	7.78 ± 0.11	7.58 ± 0.23
Sulphate*	33.33 ± 3.6	35.41 ±4.77	48.95 ± 4.77	63.54 ± 1.8	639.58 ± 3.6	654.16 ± 1.8
Chloride*	8.11 ±0.5	12.33 ± 1.05	14.7 ± 1.82	13.01 ± 1.17	13.51 ± 0.29	13.68 ± 1.34
Phosphate*	1.97 ± 0.08	1.67 ± 0.12	1.69 ± 0.12	2.22 ± 0.08	3.04 ± 0.21	2.22 ± 0.08
Sodium (ppm)	5.43 ± 0.05	1.36 ± 0.15	3.06 ± 0.89	1.83 ±0.11	6.23 ± 0.85	6.03 ± 0.57
Potassium (ppm)	1.23 ± 0.05	0.16 ± 0.05	0.4 ± 0.1	0.26 ± 0.05	1.56 ± 0.05	1.13 ± 0.05

NB: The values of all parameters marked with asterix (*) are represented in mg/l

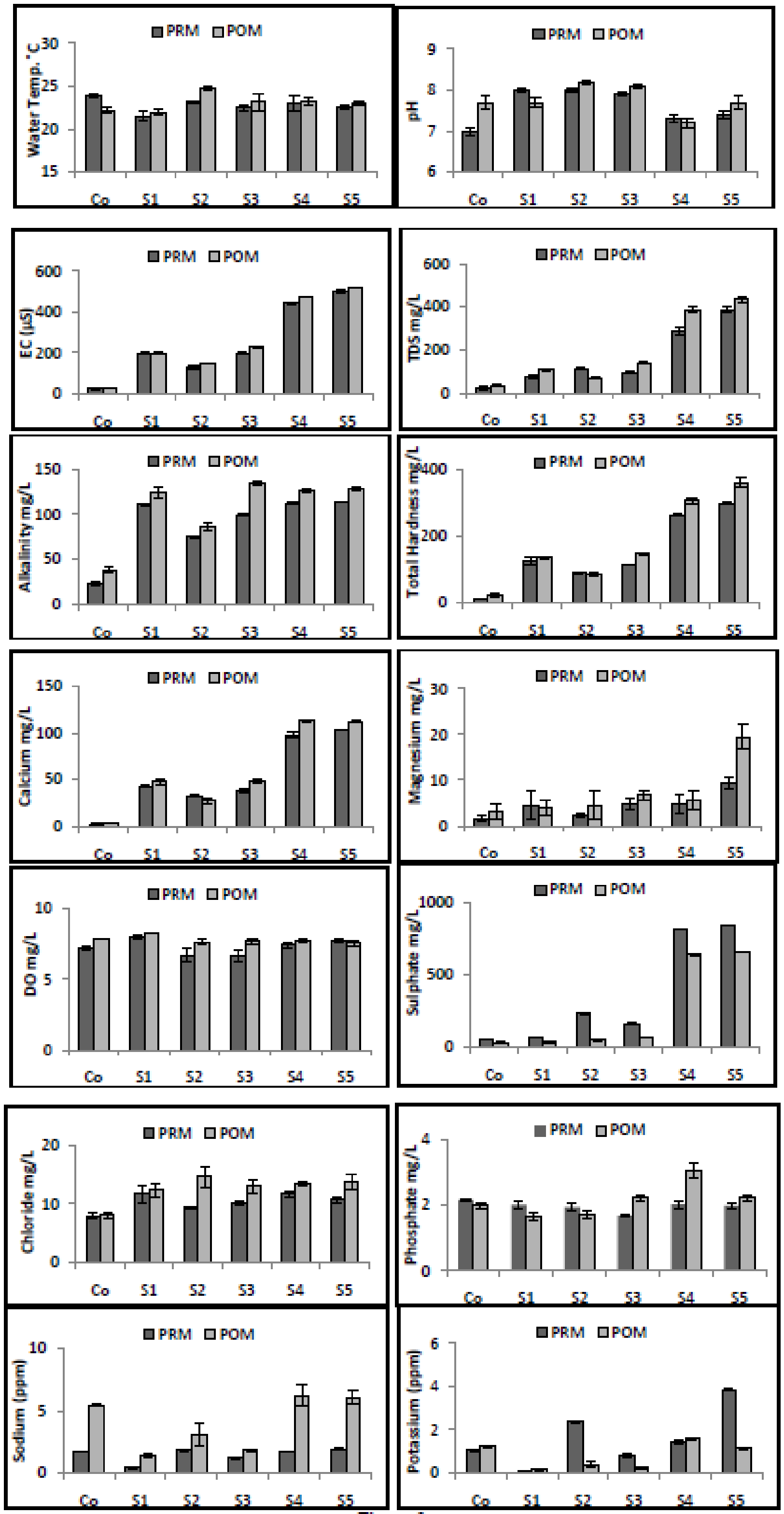

Figure 5.4: Graphical presentation of different physico-chemical parameter analysed during the study period

5.5.1.4 Average values of various water quality parameters in three seasons

The average values of various water quality parameters of water samples collected from different locations in Jaintia Hills during Winter, Pre-monsoon and Post-monsoon seasons are presented in Table 5.7 a & b.

Table 5.7a & b: Average values of various water quality parameters in three seasons from limestone mining area of East Jaintia Hills

5.7a: Temp., pH, EC, Turbidity, Total Solids, Total Alkalinity, Total Hardness, and Calcium

Sl. no.	Sampling & Location	Season	WT (^{0}C)	pH	EC (µS/cm)	T (NTU)	TS (mg/l)	TA (mg/l)	TH (mg/l)	Ca (mg/l)
1	Mihchariang	Winter	18.2	8.0	205.0	0.85	150.0	142.6	232.6	49.9
		Pre-Monsoon	21.3	8.1	168.6	5.33	103.3	109.0	120.6	44.8
		Post-Monsoon	20.0	7.9	179.7	4.9	123.2	134.4	198.7	47.5
		Mean	19.83	8.00	184.43	3.69	125.50	128.67	183.97	47.40
2	Wah Rkhiang	Winter	16.8	7.6	471.3	0.78	383.3	104.0	298.6	70.6
		Pre-Monsoon	22.6	8.1	103.0	30.7	73.33	76.3	67.3	17.3
		Post-Monsoon	18.0	8.0	231.0	14.5	83.2	78.3	123.2	45.9
		Mean	19.13	7.90	268.43	15.33	179.94	86.20	163.03	44.60
3.	Wah Pom Pa	Winter	18.1	7.7	305.3	4.5	223.3	173.3	282.0	61.6
		Pre-Monsoon	22.1	7.9	163.0	55.7	126.67	109.67	107.3	35.88
		Post-Monsoon	19.2	7.9	211.0	45.9	188.1	123.3	210.1	55.9
		Mean	19.80	7.83	226.43	35.37	179.36	135.42	199.80	51.13
4.	Wah Myntdu Jowai (Control)	Winter	13.2	8.2	29.33	1.64	50.0	52.33	58.0	5.05
		Pre-Monsoon	23.3	7.8	25.0	11.09	23.33	36.0	24.0	6.17
		Post-Monsoon	18.0	8.1	22.1	9.2	31.6	44.5	38.4	5.3
		Mean	18.17	8.03	25.48	7.31	34.98	44.28	40.13	5.51

5.7b: Magnesium, Sulfate, Chloride, Nitrate, Phosphorus, Sodium, Potassium, DO and BOD

Sl. no	Sampling & Location	Season	Mg (mg/l)	SO_4 (mg/l)	Cl (mg/l)	NO_3 (mg/l)	P (mg/l)	Na (ppm)	K (ppm)	DO (mg/l)	BOD (mg/l)
1	Mihchariang	Winter	26.2	30.4	11.9	10.6	3.8	0.37	0.13	8.66	2.95
		Pre-Monsoon	2.11	24.1	14.5	6.4	10.0	0.87	0.17	7.72	1.14
		Post-Monsoon	7.8	18.4	12.2	9.8	7.0	0.67	0.19	7.98	2.10
		Mean	12.04	24.30	12.87	8.93	6.93	0.64	0.16	8.12	2.06
2	Wah Rkhiang	Winter	29.7	182.8	17.3	16.6	4.4	22.6	2.83	10.8	4.90
		Pre-Monsoon	5.82	100.4	13.4	5.86	11.5	1.97	1.10	7.45	1.41
		Post-Monsoon	24.5	177.4	14.3	12.7	9.2	8.8	1.88	8.23	3.2
		Mean	20.01	153.53	15.00	11.72	8.37	11.12	1.94	8.83	3.17
3.	Wah Pom Pa	Winter	31.1	201.0	12.1	11.5	4.5	5.07	0.43	8.39	2.68
		Pre-Monsoon	4.31	123.8	15.12	7.26	12.42	1.67	0.73	7.72	1.54
		Post-Monsoon	23.5	166.7	13.1	8.9	12.0	3.7	0.65	6.61	1.99
		Mean	19.64	163.83	13.44	9.22	9.64	3.48	0.60	7.57	2.07
4.	Wah Myntdu Jowai (Control)	Winter	11.0	18.5	8.77	9.05	3.7	3.67	1.83	8.93	0.4
		Pre-Monsoon	2.09	6.19	9.76	1.81	9.32	3.13	0.87	7.72	1.34
		Post-Monsoon	8.2	12.2	8.9	7.9	6.7	2.9	1.01	6.3	1.12
		Mean	7.10	12.30	9.14	6.25	6.57	3.23	1.24	7.65	0.95

5.5.1 5 Description of different water quality parameters in relation to limestone mining

Water temperature: The minimum average temperature recorded during the study was 21.50 ºC ±0.56 during pre-monsoon and maximum temperature was 24.70 ºC ± 0.27 during post-monsoon. During the study period, it was observed that water temperature during post-monsoon gradually increased as compared to pre-monsoon. During winter the temperature was recorded lowest (between 12.6 to 20.0 ºC) at all sampling locations.

pH: The water samples from the studied area are generally neutral to moderately alkaline in nature having pH ranged from 7±0.11 to 8±0.05 during the pre-monsoon and 7.2±0.11 to 8.2±0.05 during post-monsoon and winter 7.6 to 8.0. Similar studies have been done at other limestone mining sites in the country. Study at Biramitrapur limestone and dolomite mines showed slightly alkaline in nature having pH ranging from 7.0 to 7.9. At all locations pH values slightly increased from pre-monsoon to post-monsoon and even more in winter season. The alkaline nature of water is due to limestone mining. Since, major chemical constituent of limestone is calcium carbonate which on coming in contact with water generates alkalinity. In contrary to this, pH of water in the nearby coal mining area is highly acidic.

Electrical Conductivity (EC): The EC at the control station was documented with a minimum value of 22.66 ±0.57 μS, 27.33 ±2.3 μS and 471 μS during pre-monsoon and post-monsoon and winter, respectively. The maximum EC was in winter. High high EC during winter season may be due to elevated quantity of dissolved alkaline ions in them (sources being waste discarded into the water bodies from the cement plants).

Total Dissolved Solids (TDS): The TDS concentration in all sampling sites increases gradually in winter from premonsoon to post-monsoon. Limestone rock disintegration could be the reasons for these increases in dissolve ions in these water bodies. This could also be attributed due to the additions of more organic and inorganic ions from the contaminated water discarded in these water bodies by the cement plants. All sampling stations were well below the set standard limit value of 500mg/l but approaching the limit in winter season.

Alkalinity: All the water samples analysed for alkalinity showed zero phenolphthalein alkalinity and have methyl orange alkalinity only for both the sampling seasons. This indicates that the alkalinity of the samples are due to bicarbonate only and not due to carbonate and hydroxide ions.

Total Hardness: As per water hardness classification; water samples having hardness (as CaCO3) value ranged from 0-75, 75-150,150-300 and above 300 are classified as soft water, moderately hard, hard and very hard water. Among the investigated water samples, control stations possess soft characteristic throughout the studied period. Some water samples possess a hard characteristic.

Calcium: Calcium is a cation. The maximum calcium concentration during pre-monsoon was recorded in (104.57±1.75 mg/L) and in S4 (112.98±1.75mg/L) during the post-monsoon season. Calcium concentration slightly increases in all sampling stations. Calcium concentration at some locations crossed the standard limits (BIS: 75 mg/L) in all seasons.

Magnesium: Magnesium concentration was reported to be lesser than the calcium values in all cases. Magnesium content investigated in all samples was found within the permissible limit of 30 mg/L. During pre-monsoon and post-monsoon period, a maximum magnesium concentration was 9.29±1.27 mg/L and 19.43±2.73mg/L, respectively.

Dissolve oxygen (DO): In the present analysis it was observed that, the average DO value at all sampling stations ranges from 6.64±0.4 mg/L to 7.98±0.11 mg/L during pre-monsoon and 7.58±0.23 mg/L to 8.25±0 mg/L during post-monsoon. The high DO content in all sampling stations may be due to the shallowness of the flowing water bodies caused by the wide sand, sediment and rocks depositions on the streams bed, thus causing the water to be saturated with oxygen. Water temperature could also play an important role for high DO content in these water bodies.

Sulphate: Sulphate is a naturally occurring ion in almost all kind of water bodies. However, its concentrations of more than 200mg/L are objectionable for any domestic purposes. During pre-monsoon period, sulphate concentration crossed the prescribed limit. Whereas during post-monsoon season, at some locations it exceeded the standard limits. Throughout the study period, it was found that only the sulphate concentration was tumbling during post-monsoon season when compared to pre-monsoon period. The main source of sulphate is due to dissolution of sulphate mineral present in limestone's rock.

Chloride: Chloride concentration differs in water samples collected from different sources and it is an indicator of contamination. Encroachment of anthropogenic waste in any water bodies tends to accelerate the chlorine concentration. All water samples investigated for chloride were within the standard limits (BIS: 250 mg/l), which indicates less chloride contamination in all water samples. The minimum chloride concentration was 7.99±0.49 mg/L at control stations during pre-monsoon. The maximum concentration was during postmonsoon at S2 (14.7±1.82 mg/L). Increasing chloride concentration increases the electrical conductivity of the water.

Phosphate: The concentrations of phosphate in all samples investigated from limestone mining area were found to be of lowest order compared to all other ions. During pre-monsoon season, concentration of phosphate ranged from 1.67±0.04 mg/l to 2.02±0.12 mg/l whereas during post-monsoon it ranges from 1.67±0.12 mg/L to 3.04±0.21 mg/L. In limestone mining areas, higher phosphate concentration was recorded in both the sampling seasons. This may be due to the industrial pollutant (organic and inorganic form) from the cement plants discarded into the inland surface water bodies.

Sodium: Sodium concentration in water is generally found to be lower than that of calcium and magnesium concentration. Sodium concentration increases noticeably in the post-monsoon period as compared to pre-monsoon. The maximum average value for sodium concentration during pre-monsoon was 1.93±0.05 ppm at S5 and 6.23±0.85 ppm at S4 for postmonsoon. The elevated values of sodium at control station may be due to dissolution of rocks mineral caused by fast flowing water flowing over its rock bed.

Potassium: In this investigation, potassium concentration at all the sampling sites ranged from 0.1±0 ppm to 3.83±0.05 ppm during pre-monsoon and ranges from 0.16±0.05 ppm to 1.56±0.05 ppm during post-monsoon period.

Based on our investigation, it can be concluded that in most cases water quality as evident from elevated levels of pH, EC, TDS, Hardness, alkalinity, calcium and sulphate concentrations has deteriorated due to the mining and processing of limestone in Jaintia Hills, Meghalaya. This is true in both the seasons of study i.e. in pre-monsoon, post-monsoon and winter seasons. The deterioration in water quality has most likely resulted due to additional accumulation, transportation, mixing and dispersion of pollutants (organic or inorganic form) from the contaminating sources into the local water bodies. Water samples, particularly collected from nearby areas of cement plants were found to be highly polluted. This may be due discharge of effluent from the cement plants into these local water bodies. The overall degradation of water quality has posed serious problem on availability of potable and irrigation water in the area. In addition, the area has experienced the loss forest and biodiversity, landscape deterioration, spreading of spoils

creating wasteland, noise pollution, degradation of agricultural lands etc. due to environmental implications of limestone mining. Therefore, immediate attention towards proper management and conservation for water resources is needed by the all concerned stakeholders, particularly the mine owners and cement plant management. In order to check further deterioration, an effective plan for protection of water sources and water conservation strategy must be developed and implemented as soon as possible in the area.

Box 5.4. Effect of Limestone Mining on Water Resources

- Large scale opencast mining of limestone is taking place in Jaintia Hills of Meghalaya.
- Study found that both limestone mining and cement plants have negative impact on the physico-chemical characteristics of water of the area. Elevated levels of pH, conductivity, dissolve solids, hardness, calcium and sulphate was found in affected streams.
- The Cement plants were also found contributing towards water quality degradation.
- Mining and processing of limestone generate overburden and limestone waste materials that are disposed off in the nearby areas and pose various types of environmental problems, including adverse effect on water quality..
- However, water pollution due to limestone mining was found limited to a slight increase in pH, conductivity and turbidity etc.

5.5.2 Limestone Mining and Water Scarcity

Due to Karst topography of Meghalaya, only a few perennial surface water bodies are present in coal and limestone deposit areas leading to water scarcity in lean period. Mining of coal and limestone and establishment of cement plants in the region have further aggravated the water scarcity in the area. Due to excavation of land and disturbance of landscape, many streams in the area have become seasonal as water of streams percolates into the ground.

Some water bodies are found above ground for certain distance and then disappear due to water flowing underground. Hence, water resources in the mining area have been affected both in terms of its quantity and quality and lead to scarcity of water.

5.6 Effect of Mining on Agriculture

Before the advent of mining the people of Jaintia Hills, mostly depended on agriculture as the source of livelihood. Both settled and jhum cultivation were prevalent with crops mainly rain fed in nature. The principal crops grown were rice, maize and other cereals. Oilseed crops like sesamum, rapeseed and mustard, soybean are also cultivated for personal uses. Other important crops of Jaintia Hills include pineapple, papaya, citrus, potato, sweet potato, tapioca, chilies, turmeric, ginger, areca nut, tobacco and vegetables.

However mining, particularly of coal and limestone has spread in the state of Meghalaya adversely affected the agricultural lands and agricultural productivity in many ways. The pollution of air, water and soil caused by mining activities affect the agriculture, directly and indirectly leading to loss of agricultural land, degradation of agricultural land and plant growth and productivity. Thus, the mining activity has come into direct competition with another predominant means of livelihood including agriculture. In mining areas of Meghalaya all such ill effects of mining on agriculture are visible. A brief account of various adverse impacts of mining to agriculture sector is given below.

5.6.1 Diversion of Agricultural Land

In order to facilitate mining activities and storage of extracted minerals, a large area of good agricultural land has been diverted to other uses leading to reduction of areas under agriculture and horticulture and ultimately reduction in agricultural production. The mining activities on agricultural land in some areas, movement of vehicles through agricultural land, storage of minerals on agricultural land etc. have reduced the net agricultural land and its productivity in Jaintia Hills.

It has been reported that farmers generally lease out their agricultural lands to both locals and non-locals for coal mining in Jaintia Hills. Most of the farmers who own the land but do not have the means to carry out mining operation rent their land to others for mining. The land owner gets the rent of the land on the basis of truck or tons of coal extracted from the land.

Owing to the unique land holding system and property rights prevailing in the State, there is hardly any role of the Government in allocation and acquisition of land for mining. Before the Judgement of the Honourable Supreme Court of 3rd July 2019 the mine owners had unlimited access to extraction of minerals without following any regulation the Mines and Minerals (Development and Regulation) Act, 1957 and various Environmental Acts applicable to mining sector had not been implemented as yet in the shadow of Sixth Schedule of Indian Constitution. Owing to all these, the mining has become a preferred investment option and has attracted many to this business. The said Judgement the Apex Court now made applicable all relevant regulations which apply in other parts of the country.

Though the Jaintias do not suffer from land alienation to people from outside, yet the emerging trend reveals that the poorer section of the society are losing their land to rich coal merchants who use both man and money power to acquire their lands. As a result, transformation of traditional economic activities from agriculture to mining has taken place in the mining areas, particularly in Jaintia Hills. This has resulted in an overall decline in agricultural activity of the people. Due to degradation of land and non-availability of labor, paddy fields are abandoned by the people who, in past traditionally depended on agriculture for their livelihood. Thus, coal mining, on one hand was able to bring wealth to some but it has rendered many without any viable long term livelihood options, hence has not benefited many of the local people. Further, due to lack of skill and expertise in newer occupational activities and also lack of working capital for investment the local people are finding difficulty in switching over to other occupations for their sustenance.

This has reportedly resulted in deterioration of social bonding which once existed among the local people. Mining has also caused the disintegration of community land. Under old tradition and practices, the local people who did not possess any land for cultivation were provided land for farming so that they can sustain themselves and their family. However, the present trend is completely different where people are claiming these lands for coal mining. A large chunk of community land is being handed over to individuals and families.

Similarly limestone mining has also affected the livelihood of the local people of Meghalaya. Owing to quick revenue obtained from limestone mining, to a certain extent a decline in traditional agricultural practices has been observed in East Jaintia Hills. Daily deposition of dust on the roof top generated from cement plants established in the area has been resulting in contamination of water and degradation of land.

Hence, due to reduction in the area of agricultural land, degradation of agricultural land, and shortage of labour force in agriculture, the farming practices in the mining area have been noticed severely affected. Mining has resulted in a decline in the traditional agricultural practices that once provided social and institutional infrastructure to harmonize the regional ecosystems. The farming communities who have not shifted to other livelihood activities have suffered to a greater extent in terms of losing their agriculture fields to mining, degradation of their agricultural fields and less productivity and income.

5.6.2 Degradation of Agricultural Land

Contamination of soil with pollutants (solid, liquid and gaseous) emanating from mining activities has degraded the agricultural land in Meghalaya. Degradation of agricultural land is more prominent in Jaintia Hills where extensive mining of coal and limestone has been taking place for decades. Mining of both minerals (coal and limestone) have adversely affected the soil of the area. However, the effects of coal and limestone are different in nature and extent.

The coal mining, on one hand has made the soil acidic due to contamination of acid mine drainage oozing out from coal mines, coal dumps and overburden. The limestone mining, on the other hand has changed the soil pH in alkaline range. Both, acidity and alkalinity beyond the optimum range are not good for soil and plant growth and development. Other problems such as deposition of mineral particles (coal or limestone particles), sand particles, erosion of top fertile soil, reduction in organic components of soil, increase of inorganic constituents, change in composition of soil flora and fauna etc. arise due to mining of both coal and limestone. Deposition of dust from limestone mining area and cement plants on soil and vegetation is another serious problem of the agriculture sector. Such degradation of soil and various other factors which arise due to mining do not support proper plant growth, development and productivity and thus make farming less remunerative. As a consequence, farmers in the mining areas have abandoned the agricultural activity and a large area of agricultural land is left unattended because farming on such land has become loss making livelihood option.

Figure 5.5: Photograph showing land degradation in Jaintia Hills due to coal mining and storage of coal in and around the farm land

5.6.3 Environmental Pollution and Agriculture

Air pollution is known to affect agriculture in numerous ways. It has the potential to reduce both the yield and the nutritional quality of crops. Therefore, agricultural production would fall even if there were no change in the quantity of other inputs used. There have been a number of empirical studies on effects of mining on agriculture; however such studies are limited in Meghalaya. In mining regions, the presence of high levels of suspended particulate matter is a major problem for agriculture. It is observed that when dust falls onto the plants it affects their nutrients, photosynthesis and production. It was shown that villages located near coal mines have suffered from a loss of productivity in rice cultivation because of the high presence of coal dust. Coal mining activities has also brought about a diversification in the occupation[21] of the people. The coal belt areas are throng not only by miners but also by managers, supervisors, traders, shopkeepers, truckers and others, belonging to different races and communities. Pollution by mining coupled with high density of human population and their activities in the area is also not conducive for agriculture.

Among all the agricultural crops grown in the area, rice constitutes the principal crop. During recent years rice cultivation has been affected to some extent by coal and limestone mining in the East Jaintia Hills district. Encroachment/conversion of agricultural land for other purposes such as mining; soil erosion; degradation of soil due to contamination of acid mine drainage, sand particles, coal particles etc. are some of the reasons noticed for decline of acreage and productivity in the coal mining area.

5.7 Effect on Fish and Fishing

Pollution of rivers due to mining activities by contamination of acid mine drainage, in particular has significantly reduced the aquatic resources particularly fish fauna in the mining area. This has compromised the livelihood of the local people traditionally dependent on fishing. The local fishing business has further suffered by import of fishes from other states. Fishing for many of the villagers in Meghalaya is an important activity for livelihood, sustenance and entertainment. Contamination of rivers in the area by Acid mine drainage has significantly caused a decline in fish production which has compromised livelihood of the local population dependent on this activity.

5.8 Impact of Mining on Human Health

The majority of health problems in mining regions are caused by air and water pollution and accidents at sites. The environment becomes contaminated from the release of dust generated by blasting and excavation, and the dumping of mine waste. Sources of air pollution in coal mining areas generally include drilling, blasting, overburden dumping, loading and unloading of coal and limestone, road transport, coal handling, exposed pit etc.[21] The health and safety problems vary from one mineral to the other, and according to the type of technology used, type of mines, and the size of operations. Because the concentration of particulate matter is high in mining areas, respiratory diseases are more common in mining workers and in people residing in mining areas[22].

The mines and people residing in coal mining areas are at an increased risk of developing heart and lung diseases, cancer, hypertensions, and kidney diseases, and mortality rates are higher in communities located in closer proximity to coal mines. Moreover, people who live close to mining areas are likely to consume contaminated water leading to multiple health problems. Some of the diseases are water-borne, including skin diseases and joint pain. Nevertheless, the majority of them are airborne, such as respiratory diseases, tuberculosis (TB), cough and cold, and eye problems. According to the local doctors, the common mine-related diseases observed in the area over the years include, but are not limited to, vector-borne diseases such as malaria; respiratory tract diseases, especially TB; skin diseases; and eye diseases, especially acute conjunctivitis.

Unorganized coal mines in Meghalaya lack basic facilities such as lighting, ventilation, safe drinking water, washing facilities, first aid box at the place of work or preventive measures against various occupational diseases. The working condition and the environment at the coal mines is such that miners are exposed to hazardous conditions for long hours every day in the underground mines. These poor conditions inflicted on the coal miners are the major causes of several physical and mental disabilities which eventually in the long run lead to occupational injuries. Exposure to high concentration of dust in these mines often leads to various types of health hazards especially respiratory disorders, in particular. Several disorders such as musculo-skeletal pain, muscle disorders related to nerves, tendons, ligaments, joints and cartilage have been associated with mining of minerals. Detail studies are needed to ascertain the effect of mining on health in mining areas of Meghalaya.

5.9 Effects of Mining on Socio-economy

There is an acute economic disparity between the people in the coal mining areas. When land is acquired for mining, the adjoining communities become jobless and this in turn results in inequality in income generation. It is important to remember that the social structure and economic life of the people are closely related, and when the economic structure changes, it is expected to bring about a change in the social organization of the people. These modifications in the context of rural social structure have taken place since the intrusion of coal mining in the area. Mining disturbs cultural ties of the indigenous communities and also disintegrates their social and cultural identity. With the development of coal mining, the socio-cultural adjustment in the mining area is becoming worse and the issues like consumption of alcohol and drugs, prostitution, illegal activities etc. are common. Vulnerable communities find it difficult to maintain cultural continuity as the mining activities are separating them from their traditional homestead and agricultural lands. The loss of emotional connection with the land is diminishing their indigenous knowledge system established over generations.

It may be pointed out that Jaintia Hills falls within the Sixth Schedule of the Indian Constitution and hence many of the social and economic forces are practically regulated in this context. Though the Jaintias do not suffer from land alienation to people from outside, yet the emerging trend reveals that the poorer section of the society are losing their land to rich coal merchants who uses both their man and money power to acquire their lands. This has led to the disintegration of community land. Now people are claiming comunity lands for coal mining and as such much of the community land has gone to the families of individuals. Some other impacts of mining in such areas include anti-social activities, violence, social evils (drinking and prostitution), and disintegration of the family and others which remains yet to be explored.

The traditional concept of a market in a tribal society has disappeared altogether in these places. The weekly market which serves as a meeting ground for people from other areas have been replaced by the daily market, catering to the needs of both the local and non-local populations. People who at one point of time would take active part in many of the traditional festivals and practices are now shying away from them for lack of “time and space”. People are more interested in investing their time in such activities where they would gain economically [10]

Further, the past traditional agrarian economy provided a platform for women to not only contribute in the field via their labour but also control the agricultural economy. In present scenario most of the coal business is run by the male members of the community and thus has reduced the role of women in household economy and rendered them vulnerable to anti-social activities. As result, the women who enjoyed special social status in the community are at the receiving end in recent past[10].

With the concerns over unscientific, unregulated and rampant extraction of coal causing environmental degradation and hazards to human health, a ban on coal mining was imposed by the National Green Tribunal in the year of 2014. This ban was imposed following a complaint from people of neighbouring state of Assam, who cited pollution of the Kopili River in downstream areas because of coal mines in Meghalaya. The ban brought a slowdown in the local economy, employment opportunities and entrepreneurship. Thus, both mining of coal and its ban in 2014 has brought socio-economic changes of different nature in the mining areas of Meghalaya. Some of these changes in each case may be positive or negative depending on different perceptions. However, there is need to adopt a policy which can bring positive socio-economic changes in the mining area.

Based on above mentioned data of various scientific studies it can be concluded that mining, particularly mining of coal and limestone have severe effects on water resources in terms of its quality and quantity. Besides, mining has affected various other components of environment such as on land and soil, air etc. Forest, biodiversity, agriculture and agricultural production, socio-economy etc. are also severely affected in mining areas of Meghalaya.

Further, sustainable options of livelihood of the people have also been affected. Thus, the benefits of mining seem short term and limited to a small number of people.

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Publications

(Research Papers published based on the results of studies undertaken in this Project. The copies of the following papers are attached)

1. Lamare, R. Eugene and **O. P. Singh (2014)** Degradation in water quality due to Limestone mining in East Jaintia Hills, Meghalaya, India. *Intl. Res. J. of Envtl. Sci. 3 (5): 13-20 (ISSN 2319- 1414).*

2. Lamare, R. Eugene and **O. P. Singh (2014)** Evaluation of water quality in Thadlaskein Lake, West Jaintia Hills, Meghalaya, India. *J. Chemical, Biological and Physical Sci. 4:2651-2656 (E- ISSN:2249- 1929).*

3. Lamare, R. Eugene and **O. P. Singh (2016)** Limestone Mining and its environmental implications in Meghalaya, India. *ENVIS Bulletin Himalayan Ecology 24: 87-100. (ISSN: 0971-7447 (P) ISSN: 2455-6815 (O).*

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Degradation in Water Quality due to Limestone Mining in East Jaintia Hills, Meghalaya, India

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Abstract

Meghalaya possesses 9% of the country total limestone reserves. Of which, East Jaintia Hills district has the maximum deposits. Limestone rock mining in the district started about a decade ago to meet the requirements of the cement plants of the area. In recent years, number of cement plants and quantum of limestone mining have increased drastically leading to severe environmental problems ranging from deforestation and degradation of land to water pollution and water scarcity. This study reports the impact of limestone mining on water quality based on analyses of various physico-chemical parameters of water samples of the area and its comparison with the results of unaffected water body. Analysis was done during the Pre-monsoon and Post-monsoon seasons of 2013, from five different locations in the vicinity of the mining area. The water samples from Myntdu river headwater were selected as a control. It was found that water samples analysed from the vicinity of limestone quarry and cement plant showed an elevated levels of pH, EC, TDS, total hardness, alkalinity, calcium and sulphate concentrations etc. with reference to those of control samples. The study revealed that open cast mining of limestone rock's and direct contact of wastewater from the cement plants into the water bodies does have a negative impact on the physico-chemical characteristics of the waters of the area. Thereby, indicating a serious problem on availability of clean water in the area.

Keywords: Limestone mining, cement plants, water quality, Jaintia hills, Meghalaya.

Introduction

Meghalaya is geographically characterized by an Archaean gnessis complex. Hence, the state has rich deposits of mineral resources such as coal, limestone, Sillimanite and Uranium etc[1]. Meghalaya possess 9% deposits of the total limestone resources of the country[2]. It is mainly distributed along the southern fringe of the state. Extensive mining of limestone began about a decade ago to meet the requirements of cement manufacturing plants, which grew exponentially in the recent past in Jaintia Hills area of Meghalaya. Limestone is the second most important mineral extracted in the state after coal.

Mining of natural aggregates whether in small/large scale are unsurprisingly destructive to the environment[3]. Limestone mining is progressively growing at present due to the escalating numbers of cement plant industries. Preliminary observations reveal that limestone mining has tremendously degraded the ecosystem of the area causing severe environmental impact such as deforestation, removal of top fertile soil, disturbances of the surrounding ecosystem near the mining sites as well as contamination of the water in the nearby area. Coal mining impact on water quality of the region has been adequately investigated[4-6]. Limestone rock mining and its probable impact on water quality has not been studied in Meghalaya. Hence, we have undertaken the study to analyze the impact of limestone mining on different components of environment of Jaintia Hills. In this paper we report the impact of limestone mining on the water quality of the area.

Material and Methods

Study Area: Limestone mining in East Jaintia Hills District starts from Nongsning village to Lumshnong along the NH.44 which is at a distance of approximately 130 Km from the Shillong city (State Capital). The area has the richest limestone deposits in the state. At present, limestone mining is being carried out extensively by eight cement plant factories (companies' own quarrying sites) as well as by the private land owners of the area.

Sample Collection: Water samples was collected during the Pre-Monsoon (April-May) and Post-Monsoon (October-November) seasons of 2013, from five different sampling stations in the vicinity of limestone mining area and from Myntdu River Headwater as control, by Grab sampling method. Of the five sampling sites (Table-1), three sampling stations S1, S2 and S3 were near the limestone quarry sites whereas S4 and S5 were from the water bodies contaminated by the wastewater from cement industries. The latter sources are now no longer used for drinking and other domestic purposes due to their contamination by the waste from cement plant.

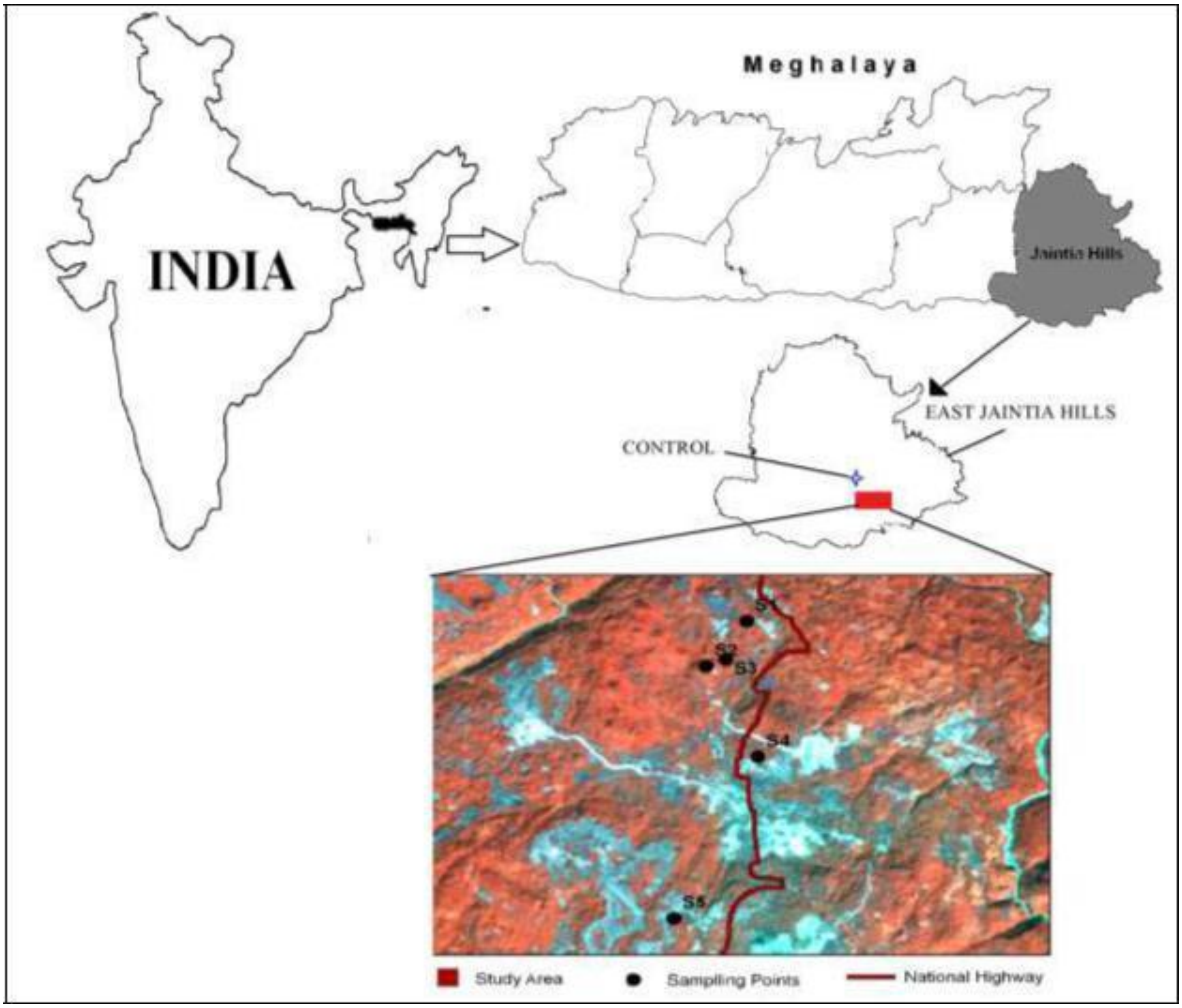


Figure-1
Map showing the study area (without scaling)

Methodology: Sampling of water was done following the standard procedures. Water quality parameter like water temperature, pH and EC was determined on the spot using EUTECH PCTestr 35. Analytical parameters like Total dissolve solids (TDS), alkalinity, total hardness, calcium, magnesium, dissolve oxygen (DO), sulphate, inorganic phosphate and chloride were analyzed in the laboratory following the standard methods[7-9]. Sodium and Potassium were estimated using Microprocessor Flame Photometer (ESICO) Model 1381.

Results and Discussion

General Environmental implications of limestone mining in Jaintia Hills: Extraction of limestone rocks in the region has undeniably brought employment opportunities and revenues for the local communities. But limestone mining has also brought an inevitable dilapidation to the environment of the area. The types and extent of environmental degradation varies from area to area with severe degradation in the environmental health of the area. The thick native vegetation cover has been denudated resulting great loss of the rich biodiversity of the area. Excavation has resulted in removal of the fertile top soil and generations of huge amount of spoil or overburden generally in the form of gravel, coarse sand, fragmented rock pieces etc, which has deteriorated the aesthetic beauty of the proximate landscape. A large area has become unusable due to spreading of mine spoil and overburden. Limestone rocks are disintegrated into smaller rock size using drilling machines and dynamite, causing hefty noise pollution. Heavy and daily blasting may also has resulted in crack formation on the geological rock, which in long run will certainly influence the availability of surface and ground water in and around the mines. The region at present is already facing an acute shortage of water availability, particularly during the dry season. Pollution of surface water by limestone mining and cement plants has further deteriorated the situation.

Table-1
Details of different sampling sites from where water samples was collected for the present study

Sampling Stations	**Water Bodies Local Name**	**Location**	**GPS Reading**	**Stations Description**
Control (Co)	Myntdu	Jowai	N25^0 47′49.7″ E92^0 20′93.7″	Situated at 200-300 m south of headwater. Rocky river bed. Away from mining activities and heavy anthropogenic disturbances
S1	Mih-Chariang	Nongsning	N25^0 24′67.7″ E92$^{\upsilon}$ 37′71.9″	Only sources of drinking water to the nearby area. At least 50 -70 m south of one quarry sites. Large volume of mine water emanating from the mining sites can be seen contaminating the sources during rainy seasons.
S2	Wah-Rkhiang	Mynkree	N25^0 23′56.8″ E92^0 37′57.4″	Situated alongside the limestone quarry. Streams bed is covered with a thick sand deposition.
S3	Pom-Pa	Mynkree	N25^0 23′06.6″ E92$^{\upsilon}$ 37′89.2″	Situated on the side of another quarry. The streams bed and bank are rugged, deposited with stone and gravel of different size.
S4	Jynrong	Wahiajer Narpuh	N25^0 19′61.3″ E92$^{\upsilon}$ 39′11.3″	Situated inside the forest at least 1.5 Km south from one of the cement plant. Heavy sand deposition observed on stream bed. Once the source of water supply to the nearby locality.
S5	Umjri	Lumshnong	N25^0 17′97.8″ E92$^{\upsilon}$ 36′32.2″	Situated approximately 0.5 to 1 km south of another cement plant. Once the source of drinking water to the Lumshnong locality. Dull appearances of the water body.

Degradation in water quality due to limestone mining: Water quality analysis gives us an idea about the health of the water bodies. Thus water samples from two different seasons of the year were analysed to see the changes in its quality. The pre-monsoon and post-monsoon water quality data are summarized in table-2 and table-3, respectively. The graphical representations of different physico-chemical water parameters are also presented in figure-2. The details various parameters are discussed below:

Water temperature: The minimum average temperature recorded during the study period was 21.5^{0}C ±0.56 during pre-monsoon at S1 and maximum temperature was 24.7^{0}C ± 0.27 at S2 during post-monsoon. During the study period, it was observed that water temperature during post- monsoon gradually increases as compared to pre-monsoon with the exception of the control sites. The variation in water temperature at different locations may be attributed to the altitudinal variations of the sites.

pH: The water samples from the studied area are generally neutral to moderately alkaline in nature having pH ranged from 7±0.11 to 8±0.05 during the pre-monsoon and 7.2±0.11 to 8.2±0.05 during post-monsoon. Similar studies have been done at other limestone mining sites in the country. Study at Biramitrapur limestone and dolomite mines showed slightly alkaline in nature having pH ranging from 7 to 7.9[10]. Except for S1 and S4, pH values slightly increased from pre-monsoon to post-monsoon in all sampling sites. However, this alkaline nature of water may be due to limestone mining. Since, major chemical constituent of limestone is calcium carbonate which on coming in contact with water generates alkalinity. In contrary to this, pH of water in the nearby coal mining area is highly acidic.

Conductivity (EC): The EC at the control station was documented with a minimum value of 22.66±0.57 µS and 27.33±2.3 µS during pre-monsoon and post-monsoon respectively. The maximum EC was at S5 for both the seasons. The water samples S1, S2 and S3 locations show relatively low EC, implying the presence of reduced level of ionic species as compared to the other two sites. Whereas high EC value in S4 and S5 for both the seasons, may be due to elevated quantity of dissolved ions in them (sources being waste discarded into the water bodies from the cement plants).

Table-2
Pre-Monsoon season (PRM) data for different parameters of different stations from the study area

Sampling Stations / Parameters	**Control (Co)**	**S1**	**S2**	**S3**	**S4**	**S5**
Water Temp. C	23.9± 0.14	21.5 ± 0.56	23.1 ± 0.07	22.5 ± 0.28	23.0 ± 0.91	22.5 ± 0.21
pH	7.0 ± 0.1	8.0 ± 0.05	8.0 ± 0.05	7.9 ± 0.05	7.3 ± 0.1	7.4 ± 0.11
EC (NTU)	22.66 ± 0.57	196 ± 4.35	129.33 ± 8.38	197 ± 5.19	443 ± 3	502 ± 5.19
TDS*	23.33 ± 5.77	76.66 ± 11.54	113.33 ± 5.77	96.66 ± 5.77	286.66 ± 20.81	386.66 ± 15.27
Alkalinity*	23 ±1.73	110.33 ±1.52	74.66 ±0.57	99.66 ± 0.57	112 ± 1	114 ± 0
Total Hardness*	12.66 ± 1.15	126.66 ± 11.54	91.33 ± 3.05	115.33 ± 2.3	264.66 ± 4.61	299.33 ± 1.15
Calcium*	2.52 ± 0.84	43.45 ± 0.97	32.8 ± 0.84	38.12 ± 1.28	98.12 ± 2.56	104.57 ± 1.75
Magnesium*	1.54 ± 0.58	4.41 ± 3.14	2.29 ±0.25	4.89± 1.25	4.7 ± 2.08	9.29 ± 1.27
Dissolve Oxygen*	7.18 ± 0.11	7.98 ± 0.11	6.71 ± 0.5	6.64 ± 0.4	7.44 ± 0.2	7.78 ± 0.11
Sulphate*	56.25 ± 3.12	63.54 ± 1.8	232.29 ± 6.5	162.5 ± 3.12	814.58 ± 1.8	840.62 ± 3.12
Chloride*	7.99 ± 0.49	11.66 ± 1.52	9.33 ± 0.28	10.16 ± 0.28	11.66 ± 0.57	10.66 ± 0.57
Phosphate*	2.16 ± 0.04	2.0 ± 0.12	1.94 ± 0.12	1.67 ±0.04	2.02 ± 0.12	1.97 ± 0.08
Sodium (ppm)	1.73 ± 0.05	0.46 ± 0.05	1.83 ± 0.05	1.2 ± 0.1	1.73 ± 0.05	1.93 ± 0.05
Potassium (ppm)	1.06 ±0.05	0.1 ± 0	2.36 ± 0.05	0.8 ± 0.1	1.43 ± 0.05	3.83 ± 0.05

NB: The values of all parameters marked with asterix (*) are represented in mg/l

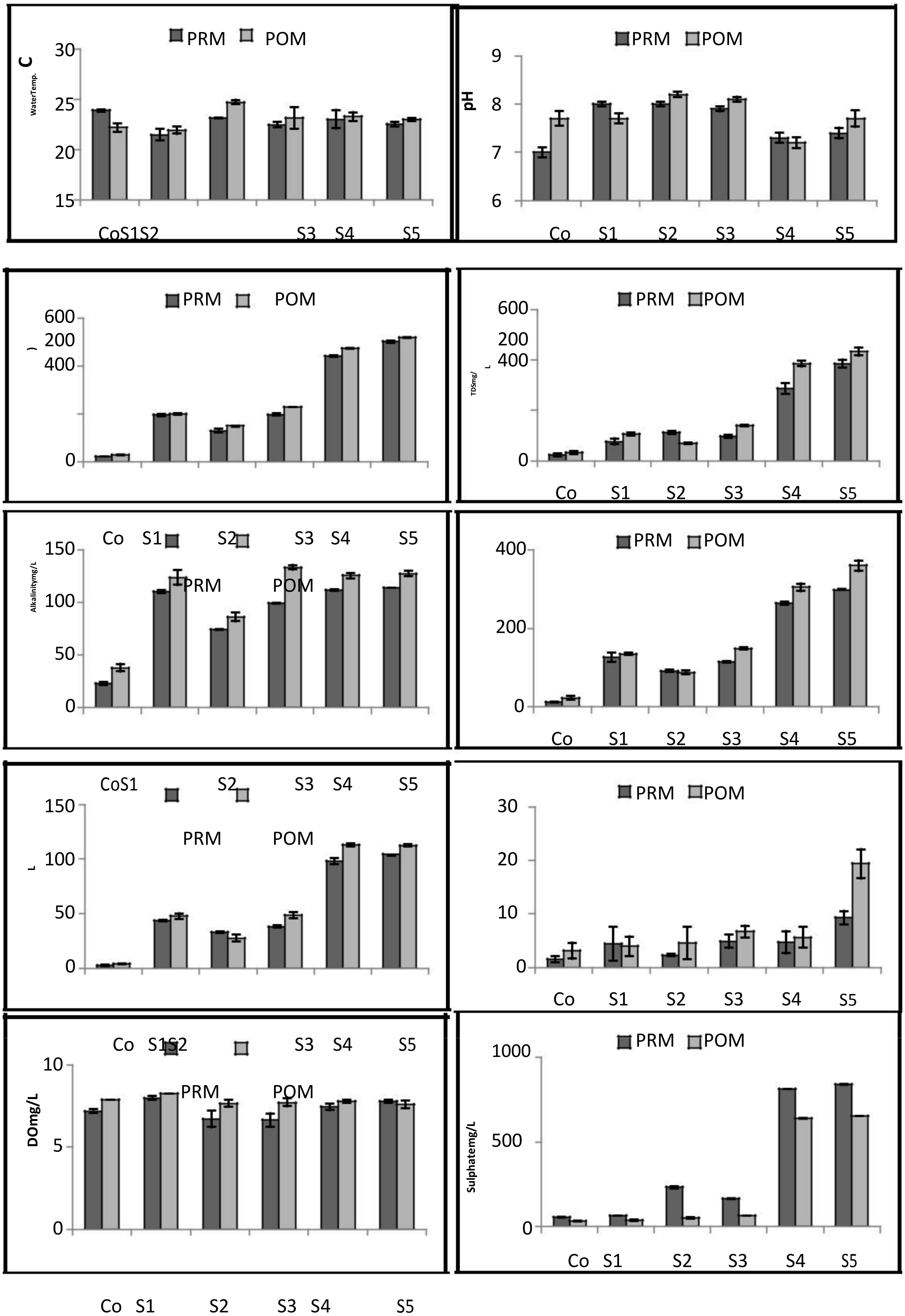
Table-3
Post-Monsoon season (POM) data for different parameters of different stations from the study area

Sampling Stations / Parameters	**Control (Co)**	**S1**	**S2**	**S3**	**S4**	**S5**
Water Temp. C	22.2 ± 0.42	21.9 ± 0.35	24.7 ± 0.21	23.1 ± 1.06	23.3 ± 0.42	23 ± 0.14
pH	7.7 ± 0.15	7.7 ± 0.1	8.2 ± 0.05	8.1 ± 0.05	7.2 ± 0.11	7.7 ± 0.17
EC (NTU)	27.33 ± 2.3	199 ± 3	149 ± 1.73	228.33 ± 1.15	474 ± 2	519.66 ± 2.51
TDS*	33.33 ± 5.77	106.66 ± 5.77	70 ± 4.1	140 ± 4.1	386.66 ± 11.54	433.33 ± 15.27
Alkalinity*	38 ± 3.46	124 ± 7	86.33 ± 4.04	133.66 ± 2.08	125.66 ± 2.51	127.66 ± 2.51
Total Hardness*	22.66 ± 5.03	135.33 ± 3.05	87.33 ± 5.03	148.66 ± 3.05	305.33 ± 9.45	360.66 ± 13.61
Calcium*	3.92 ± 0.48	47.65 ± 2.56	27.47 ± 3.18	48.5 ± 2.7	112.98 ± 1.75	112.42 ± 0.97
Magnesium*	3.12 ± 1.49	3.97 ± 1.82	4.55 ± 3.04	6.7 ± 1.08	5.64 ± 1.96	19.43 ± 2.73
Dissolve Oxygen*	7.85 ± 0	8.25 ± 0	7.65 ± 0.2	7.71± 0.23	7.78 ± 0.11	7.58 ± 0.23
Sulphate*	33.33 ± 3.6	35.41 ±4.77	48.95 ± 4.77	63.54 ± 1.8	639.58 ± 3.6	654.16 ± 1.8
Chloride*	8.11 ±0.5	12.33 ± 1.05	14.7 ± 1.82	13.01 ± 1.17	13.51 ± 0.29	13.68 ± 1.34
Phosphate*	1.97 ± 0.08	1.67 ± 0.12	1.69 ± 0.12	2.22± 0.08	3.04 ± 0.21	2.22 ± 0.08
Sodium (ppm)	5.43 ± 0.05	1.36 ± 0.15	3.06 ± 0.89	1.83 ±0.11	6.23 ± 0.85	6.03 ± 0.57
Potassium (ppm)	1.23 ± 0.05	0.16 ± 0.05	0.4 ± 0.1	0.26± 0.05	1.56 ± 0.05	1.13 ± 0.05

NB: The values of all parameters marked with asterix (*) are represented in mg/l

Total Dissolved Solids (TDS): The TDS concentration in all sampling sites increases gradually, except for S2, from pre-monsoon to post-monsoon. Water samples at S1, S2 and S3 point up a comparatively little higher TDS concentration for both seasons as compared to the control stations. Limestone rock disintegration could be the reasons for these increases in dissolve ions in these water bodies. Whereas maximum concentration was found in S4 and S5, this is due to the additions of more organic and inorganic ions from the contaminated water discarded in these water bodies by the cement plants. All sampling stations were well below the set standard limit value of 500mg/l but approaching the limit in case of S5 during post-monsoon season.

Alkalinity: All the water samples analysed for alkalinity showed zero phenolphthalein alkalinity and have methyl orange alkalinity only for both the sampling seasons. This indicates that the alkalinity of the samples are due to bicarbonate only and not due to carbonate and hydroxide ions. Carbonate content has been reported to be zero in the ground water sample of Vijayraghovgarh limestone mines[11]. Carbonate were always less than bicarbonates[12]. The total Alkalinity values ranges from 23±1.73 mg/L to 114±0 mg/L during pre-monsoon and with maximum alkalinity at S5. During post-monsoon, the total Alkalinity values ranges from 38±3.46 mg/L to 133.66±2.08 mg/L and S3 possess maximum alkalinity. Alkalinity value somewhat increased during the post-monsoon as compared to pre-monsoon.


PRM
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600
200
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TDSmg/
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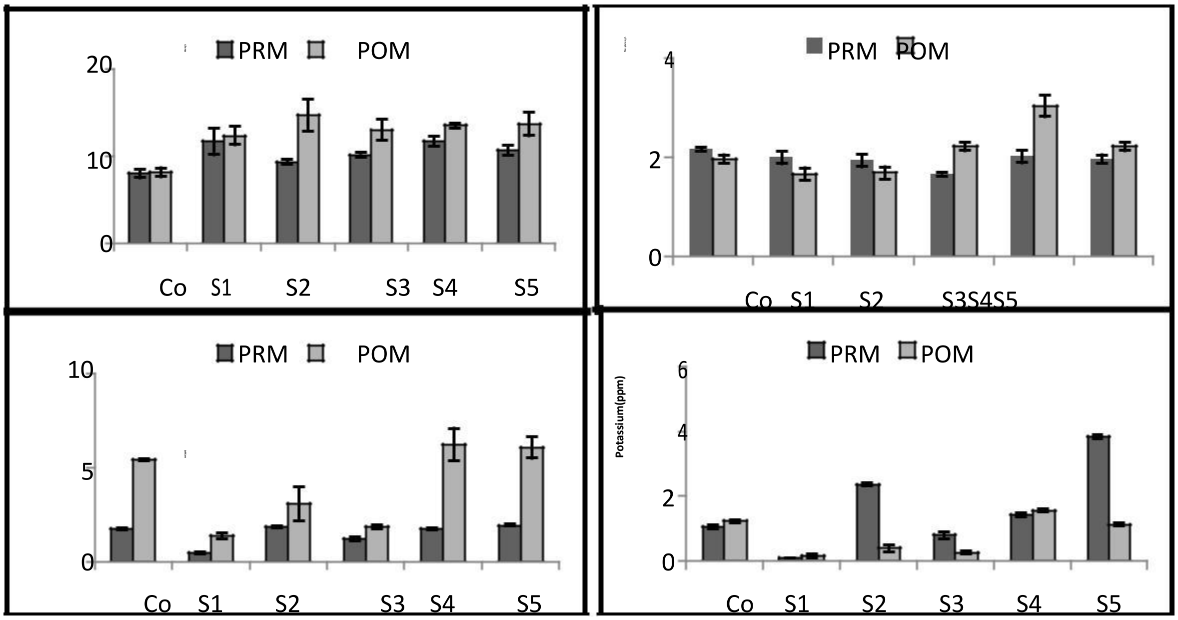

Figure–2
Graphical presentation of different physico-chemical parameter analysed during the study period

Total Hardness: As per water hardness classification; water samples having hardness (as $CaCO_3$) value ranged from 0-75, 75-150,150-300 and above 300 are classified as soft water, moderately hard, hard and very hard water. Among the investigated water samples, control stations possess soft characteristic throughout the studied period. S1, S2 and S3 are moderately hard for both the seasons. Water samples from S4 and S5 possess a hard characteristic during pre-monsoon seasons and very hard characteristic during post-monsoon seasons. Their hardness value for post-monsoon period has exceeded the prescribed limits of BIS (300mg/L).

Calcium: Calcium is a cation. The maximum calcium concentration during pre-monsoon was recorded in S5 (104.57±1.75 mg/L) and in S4 (112.98±1.75mg/L) during the post-monsoon season. Calcium concentration slightly increases in all sampling stations, excluding S2, from pre- monsoon to post-monsoon seasons. Calcium concentration for S4 and S5 has cross the standard limits (BIS: 75 mg/L) for both the seasons.

Magnesium: Magnesium concentration was reported to be lesser than the calcium values in all cases. Magnesium content investigated in all samples was found within the permissible limit of 30 mg/L. During pre-monsoon and post-monsoon period, a maximum magnesium concentration was 9.29±1.27 mg/L and 19.43±2.73mg/L at S5 respectively.

Dissolve oxygen (DO): In the present analysis it was observed that, the average DO value at all sampling stations ranges from 6.64±0.4 mg/L to 7.98±0.11 mg/L during pre-monsoon and 7.58±0.23 mg/L to 8.25±0 mg/L during post-monsoon. The high DO content in all sampling stations may be due to the shallowness of the flowing water bodies caused by the wide sand, sediment and rocks depositions on the streams bed, thus causing the water to be saturated with oxygen. Water temperature could also play an important role for high DO content in these water bodies.

Sulphate: Sulphate is a naturally occurring ion in almost all kind of water bodies. However, its concentrations of more than 200mg/L are objectionable for any domestic purposes. During pre-monsoon period, sulphate concentration at S2, S4 and S5 crossed the prescribed limits. Whereas during post-monsoon season, only S4 and S5 exceeded the standard limits. Throughout the study period, it was found that only the sulphate concentration was tumbling during post-monsoon season when compared to pre-monsoon period. The main sources of sulphate in S1, S2 and S3 may be due to dissolution of surface mineral present in limestone's rock. Limestone rock mining elevated sulphate concentration in groundwater[13]. Elevated concentration in S4 and S5 may be due to manufacturing waste discharge from the cement plants.

Chloride: Chloride concentration differs in water samples collected from different sources and it is an indicator of contamination. Encroachment of anthropogenic waste in any water bodies tends to accelerate the chlorine concentration. All water samples investigated for chloride were within the standard limits (BIS: 250 mg/l), which indicates less chloride contamination in all water samples. The minimum chloride concentration was 7.99±0.49 mg/L at control stations during pre-monsoon. The maximum concentration was during post-monsoon at S2 (14.7±1.82 mg/L). Increasing chloride concentration increases the electrical conductivity of the water[14].

Phosphate: The concentrations of phosphate in all samples investigated from limestone mining area were found to be of lowest order compared to all other ions. During pre-monsoon season, concentration of phosphate ranged from 1.67±0.04 mg/l to 2.02±0.12 mg/l whereas during post-monsoon it ranges from 1.67±0.12 mg/L to 3.04±0.21 mg/L. In limestone mining areas, higher phosphate concentration was recorded in S4 for both the sampling seasons. This may be due to the industrial pollutant (organic and inorganic form) from the cement plants discarded into the inland surface water bodies.

Sodium: Sodium concentration in water is generally found to be lower than that of calcium and magnesium concentration. Sodium concentration increases noticeably in the post-monsoon period as compared to pre-monsoon. The maximum average value for sodium concentration during pre-monsoon was 1.93±0.05 ppm at S5 and 6.23±0.85 ppm at S4 for post-monsoon. The elevated values of sodium at control station may be due to dissolution of rocks mineral caused by fast flowing water flowing over its rock bed.

Potassium: In this investigation, potassium concentration at all the sampling sites ranged from 0.1±0 ppm to 3.83±0.05 ppm during pre-monsoon and ranges from 0.16±0.05 ppm to 1.56±0.05 ppm during post-monsoon period. Concentration of potassium when compared decreases considerably at S2, S3 and S5 during post-monsoon.

Conclusion

Based on our investigation, it can be concluded that in most cases water quality as evident from elevated levels of pH, EC, TDS, Hardness, alkalinity, calcium and sulphate concentrations has deteriorated due to the mining and processing of limestone in Jaintia Hills, Meghalaya. This is true in both the seasons of study i.e. in pre-monsoon to post-monsoon seasons. The deterioration in water quality has most likely resulted due to additional accumulation, transportation, mixing and dispersion of pollutants (organic or inorganic form) from the contaminating sources into the local water bodies. Water samples, particularly collected from nearby areas of cement plants were found to be highly polluted. This may be due discharge of effluent from the cement plants into these local water bodies. The overall degradation of water quality has posed serious problem on availability of potable and irrigation water in the area. In addition, the area has experienced the loss forest and biodiversity, landscape deterioration, spreading of spoils creating wasteland, noise pollution, degradation of agricultural lands etc. due to environmental implications of limestone mining. Therefore, immediate attention towards proper management and conservation for water resources is needed by the all concerned stakeholders, particularly the mine owners and cement plant management. In order to check further deterioration, an effective plan for protection of water sources and water conservation strategy must be developed and implemented as soon as possible in the area.

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Section D: Environmental Sciences

CODEN (USA): JCBPAT **Research Article**

Evaluation of Water Quality in Thadlaskeiñ Lake, West Jaintia Hills, Meghalaya, India

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Abstract: The Thadlaskeiñ Lake is an impoundment Lentic lake located in Mukhla village of West Jaintia Hills, Meghalaya. It is one of a few designated tourist spots of the district. As per the traditional history, the lake was created by Sajar Nangli (a local Chieftain) and his follower using the end of the bows. The present study is an attempt to get a comprehensive idea of the water quality of the lake and its seasonal variations. For assessment of the lake water quality, parameters like pH, EC, TDS, TH, Ca^{2+}, Mg^{2+}, PO_4, SO_4, Cl^- and DO were analysed following standard procedures. The data on physico-chemical parameters revealed that water quality of the lake has not yet deteriorated and the measured water quality parameters were found within the permissible limits of Bureau of Indian Standard (BIS). However, there is need for constant vigil to maintain the water quality as the Thadlaskeiñ Lake is attracting large number of tourists in recent past and is under pressure due to various anthropogenic activities occurring in the vicinity of the lake.

Keyword: Water quality, Physico-chemical parameters, Seasonal variations, Thadlaskeiñ Lake, Meghalaya.

INTRODUCTION

Sajar Nangli Lake well known as Thadlaskeiñ Lake is an impoundment Lentic lake located in West Jaintia Hills, Meghalaya. It is situated at an elevation of 1375 msl and lies between $25^0$29’51.5” N and $92^0$10’21.8” E. The lake is somewhat square in shape. It is surrounded by paddy fields and open pine forests. The lake is at a distance of about 8 Km from the main town of Jowai and lies along the National Highway No. 44.

According to the traditional history, Sajar Nangli (a local Chieftain) at some point of time had incompatible differences with the King of Jaintiapur. Being human in his thought, he decided to flee from the region with his follower's in order to avoid any bloodbath. However before his departure, he and his followers dug the present day lake with the ends of bows and left the area with this memorial. The people of Mukhla Raid Lake still value the lake and practice rituals and sacrifices till date. In recent years the lake has become one of the most visiting tourist spots of the West Jaintia Hills district (Figure- 1). The prime attraction of the lake is its aesthetic beauty, cool breeze, green surrounding and overall its calm backdrop. All these make the lake a favourite picnic spot. In this study we have analysed various physico-chemical parameters of the water of Thadlaskeiñ Lake keeping in mind to generate baseline data on water quality and also considering different anthropogenic activities occurring in the vicinity of the lake.

EXPERIMENTAL

Water samples from the lake were collected during the pre monsoon (May) and post monsoon (October) period of the year 2013 following standard methods. Grab sampling method was employed for sampling of water. Pre-cleaned plastic bottles were used to collect the samples. *In-situ* measurement of parameters like pH and Electrical Conductivity (EC) was done using EUTECH PCTestr 35. Other parameters such as Total Dissolved Solids (TDS), Total Hardness (TH), Dissolve Oxygen (DO) and levels of Ca^{2+}, Mg^{2+}, PO_4, SO_4, Cl^- were estimated in laboratory following standard methods [1-3].

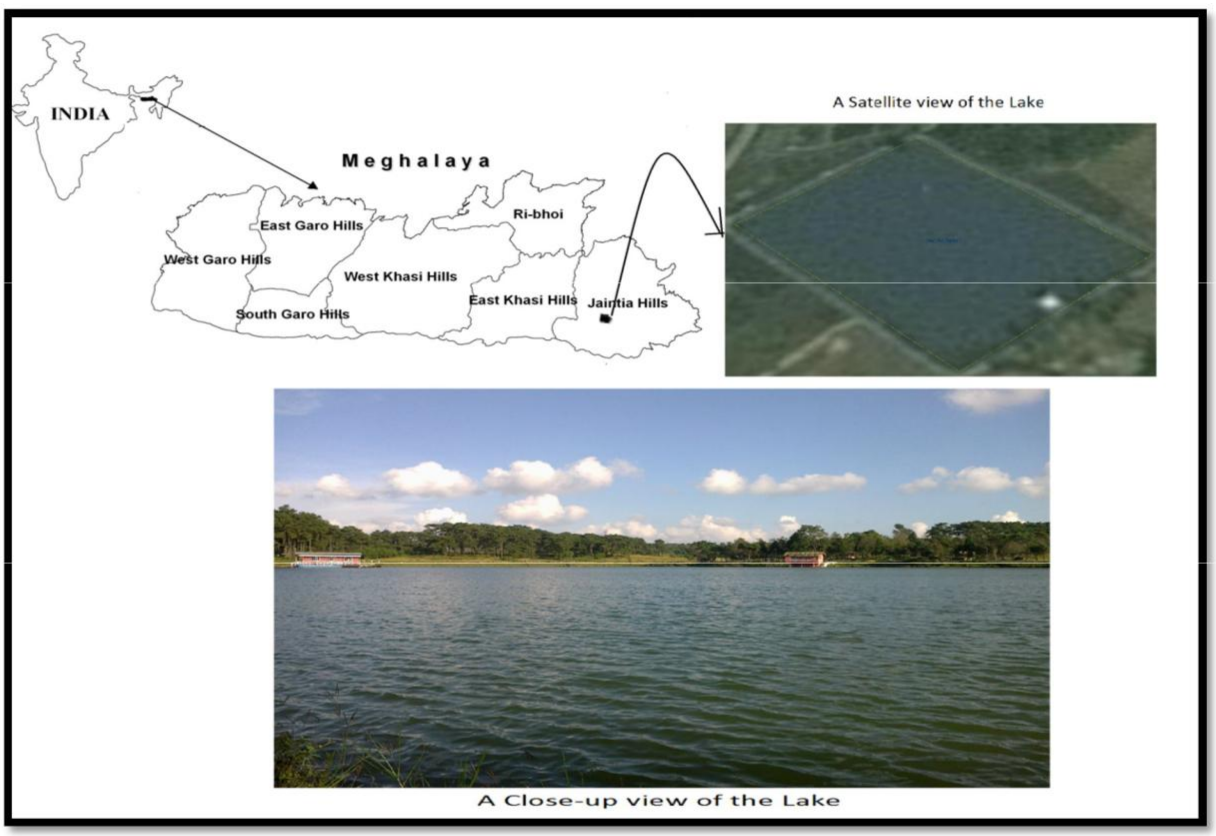

Figure- 1: Figure showing location and a view of the Thadlaskeiñ Lake

RESULTS AND DISCUSSION

Physico-chemical parameters of water samples of Thadlaskeiñ Lake were analyzed in pre monsoon (May) and post monsoon (October) seasons of the year 2013 for understanding the water quality and its seasonal variation. The data is presented in **Table 1 and Figure 2.**

Table 1: The mean value of different parameters of the Thadlaskeiñ lake water and its comparison with BIS

Parameters	Pre monsoon		Post monsoon		BIS standards
	Mean ± SD	Ranged	Mean ± SD	Ranged	IS:10500
pH	6.8±0.1	6.7-6.9	7.7±0.1	7.6-7.8	6.5-8.5
EC (μS)	12.66±0.57	12-13	11.33±0.57	11-12	-
TDS (mg/l)	33.33±5.77	30-40	23.33±5.77	20-30	500
TH (mg/l)	9.33±2.3	8-12	21.33±6.11	16-28	300
Ca^{2+} (mg/l)	1.96±0.48	1.68-2.52	3.64±0.48	3.36-4.2	75
Mg^{2+} (mg/l)	1.07±0.26	0.92-1.38	2.96±1.21	1.84-4.25	30
SO_4 (mg/l)	49.99±3.12	46.87-53.12	72.91±4.77	68.75-78.12	200
PO_4 (mg/l)	2.32±0.004	2.3-2.38	2.43±0.009	2.38-2.54	-
Cl^- (mg/l)	5.99±0.5	5.49-6.49	8.49±2	6.49-10.49	250
DO (mg/l)	7.44±0.4	7.04-7.85	7.38±0.11	7.24-7.44	-

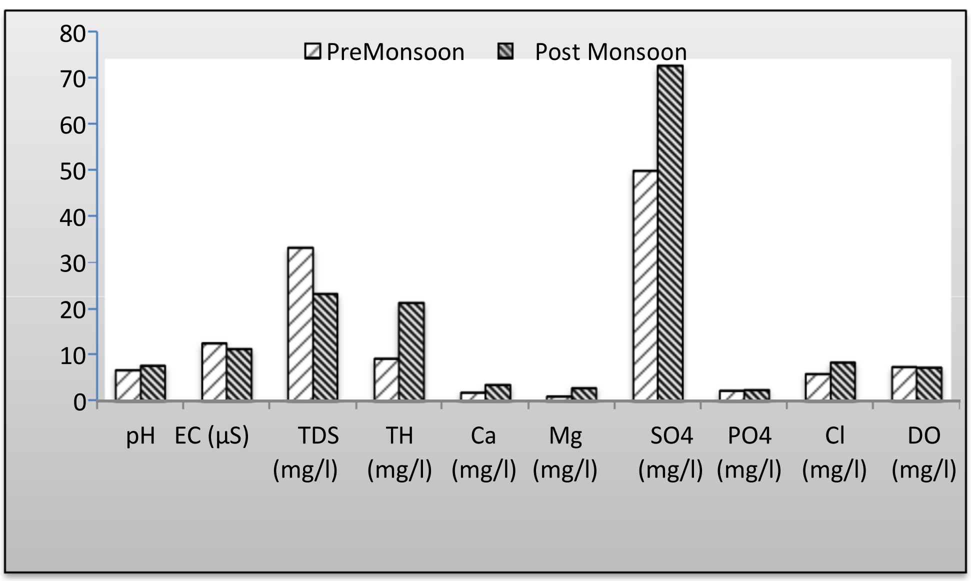

Figure 2: Graphical representation of mean values of different parameters of the Thadlaskeiñ lake water analysed during pre-monsoon and post monsoon seasons.

The study revealed that the pH of the lake water is slightly acidic (mean pH value of 6.8) during the pre-monsoon season and slightly alkaline (mean pH value of 7.7) in post monsoon season. Seasonal variations in pH may be attributed by temperature differences, accumulation of solutes in the form of carbonate/bicarbonates during rainy seasons and respiratory or photosynthesis activities. For both the seasons, overall pH of the lake is in its optimal value. The value of pH falls within the permissible limit of BIS (6.5-8.5). Ionic concentration and dissolved solid content in water determine the electrical conductivity[4]. Low electrical conductivity for both the seasons was observed in the range of a mean value of 12.66 µS (in pre monsoon) and 11.33 µS (in post monsoon) implying that the lake has only a small concentration of dissolved minerals. TDS content in the lake was reported to be higher during pre-monsoon (showing a mean value of 33.33mg/l) while lower content was observed during post monsoon season (showing a mean value of 23.33mg/l). Such a small seasonal variation in TDS, about 10 mg/l, is not significant and could be due to its dilution by the rain water during the monsoon period.

Hardness characteristics of water gave us a general idea of how easy water can form suds with soap, scale formation in water pipes or boilers. The total harness concentration of the lake is well within the limit set by the BIS (300mg/l).The lake water was found to be soft in nature having hardness mean value of 9.33 mg/l during pre-monsoon and 21.33 mg/l during post monsoon season. Sahni and Yadav[5] also reported a similar finding. Increasing hardness during post monsoon could be due the presence of calcium, magnesium and sulphate ions. In all type of water, calcium and magnesium are coupled with one another, but concentration of calcium remains generally higher than that of magnesium[6]. Calcium and Magnesium concentrations in the lake for both the seasons are within the permissible limit. Concentration of calcium and magnesium was found slightly higher in the post monsoon season. Generally, chloride concentration in natural surface water is very low. The mean values for chloride concentration during pre-monsoon and post monsoon seasons detected were 5.99mg/l and 8.49 mg/l, respectively. The chloride concentration in the lake falls within the permissible limit (BIS: 250 mg/l) indicating absence of chloride contamination sources in the vicinity of the lake.

Sulphate is found in most water bodies. But concentration beyond 200mg/l is unsuitable for drinking purposes. Sulphate content of the lake was found within the permissible limits of BIS. The sulphate ions concentration in pre monsoon was minimum and having a mean value of 49.99 mg/l and maximum with mean value of 72.91 mg/l in post monsoon. Insignificant seasonal variation in phosphate ions concentration was observed during the study period. Phosphate ion concentration was at the lowest order having mean values of 2.32 mg/l during pre-monsoon and 2.43 mg/l during post monsoon seasons. This may due to low level of decomposing organic matter and human interference. Concentration of dissolve oxygen of any water body plays an important role in determining the water quality. Higher the dissolve oxygen content of the water better is the water quality of the area apart from shallow water. The DO values of the lake changes only slightly from pre monsoon to post monsoon having mean value of 7.44mg/l and 7.38mg/l, respectively. This desirable concentration of DO may due to the low organic material content in the lake.

Several studies on quality of lake water have been carried out in past by different researchers. Results reported from analysis of water quality of Saathamcottah Lake[7], Chandola Lake[8], Ullal Lake[9], Malav Lake[10], Periyar Lake[11] and lakes in and around Coimbatore[12] described that these lakes were poor in water quality/polluted, biologically inactive in nature or unfit for human consumptions and highly eutrophic in its nature. The degradation in water quality were mainly due to different anthropogenic activities ranging from domestic/agriculture waste disposal, developmental activities and disturbances in the nearby catchment areas and influx of untreated effluent from the vicinity of the lakes. In contrast to these results, the water quality of Thadlaskeiñ Lake was found in good condition and the lake is not yet affected by various activities taking place around the area. This may be due to the least human interferences in its vicinity. Akindele[13] also reported that less impact will be on the lake if it is away from anthropogenic activities. So far the settlements and commercial activities are located fairly at a distance from the lake. However, some construction works have already started near the lake, which if not properly planed may pose threat to the water quality of the lake. It is reported that the surface water in Jaintia Hills, Meghalaya has been severely affected by coal mining. The water of several streams and rivers has become highly acidic and contaminated with sulphate, iron and other ions due to contamination with acid mine drainage (AMD) emanating from active and abandoned coal mines[14, 15]. Thus, Thadlaskeiñ Lake seems to be highly vulnerable to various types of contamination and therefore needs special attention.

CONCLUSION

Taking into account the results of physico-chemical parameters of lake water, the findings clearly signify that the lake is not yet deteriorated or polluted and has good water characteristics and no major seasonal variations occur in its water quality. All parameters investigated were within the permissible limits set by the BIS. As a result, the lake water characteristics can be regarded as still in a very good condition. However, there is a need to maintain the water quality by adapting good practices. The tourists and people of the surrounding areas are advice not to hamper the lake by throwing or disposing garbage/sewage waste in its vicinity. Villagers should be discouraged to use agrochemicals, as in long run this will pose a serious threat to the lake. Further, good forest cover and greenery should be maintained in order to sustain the quality and quantity of the lake water. Based on this study, the lake may be categorized as an oligotrophic lake.

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LIMESTONE MINING AND ITS ENVIRONMENTAL IMPLICATIONS IN MEGHALAYA, INDIA

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ABSTRACT

Meghalaya, a small state in north eastern region of India is abundantly blessed with coal and limestone. About 9% of the country's total limestone reserves are distributed in the state. Mining is carried out by open cast method of mining which is taking place at both large scale and small scale levels. The limestone mined is used chiefly for the manufacturing of cement, lime and edible lime etc. Scientific studies revealed that loss of forest cover, pollution of water, soil and air, depletion of natural flora and fauna, reduction in biodiversity, erosion of soil, instability of soil and rock masses, changes in landscape and degradation of agriculture land are some of the conspicuous environmental implications of limestone mining. In this paper we have reviewed the status of limestone mining and its environmental implications in Meghalaya, India. Results on impact of limestone mining on quality of water, soil and air, degradation of forest and availability of water are summarized and discussed. Based on overall impact of limestone mining in the area it is suggested that all stakeholders particularly the owners of mines and cement plants should give necessary attention to environmental issues prevailing in the area. Initiatives for proper management of natural resources such as water, soil and forest should be taken to halt further loss of forest cover and top soil and to prevent deterioration of water quality, soil degradation, air and noise pollution.

Keywords: Limestone mining, Cement Plants, Environment Issues and Problems, Meghalaya.

INTRODUCTION

India is a diverse country endowed with potentially rich mineral resources. According to the Indian Mineral Yearbook Report (2013), India produces around 90 minerals. Of these, 4 are fuel minerals, 11 metallic minerals, 52 non-metallic and 23 minor minerals (building and other materials). This indicates that the mining industry in India is a very important industry essential for the economic development of the country. Limestone is a non-metallic mineral and is a raw ingredient required for the manufacturing of cement, an important construction material. The total estimated resources of limestone of all categories and grades in India are 184,935 million tonnes. Of this, 14,926 million tonnes (8%) are under reserves category and 170,009 million tonnes (92%) are under remaining resources category. The state of Karnataka alone accounts for about 28% of the total limestone resources in India followed by Andhra Pradesh (20%), Rajasthan (12%) , Gujarat (11%), Meghalaya (9%), Chhattisgarh (5%) and remaining 15% by other states.

However in terms of production, the state with maximum production is Andhra Pradesh accounting about 21% of the total cement production, followed by Rajasthan (20%), Madhya Pradesh (13%), Tamil Nadu (9%), Gujarat, Karnataka and Chhattisgarh (8% each), Himachal Pradesh and Maharashtra (4% each) and the remaining 5% is contributed by Odisha, Meghalaya, Uttar Pradesh, Jharkhand, Kerala, Bihar, Assam and Jammu & Kashmir (Indian Mineral Yearbook Report, 2014). In India, cement industry alone consumed about 76% of the limestone produced, whereas 16% is used by iron and steel industry, 4% by chemical industries and remaining 4 % is used in sugar, paper, fertilizer and ferro-manganese industries. India is the second largest cement producing country in the world after China. There were 178 large cement plants having an installed capacity of 318.94 million tonnes in 2012-13 in addition to mini and white cement plants having estimated capacity of around 6 million tonnes per annum (Indian Minerals Yearbook, 2014).

Meghalaya, one of the eight states of North-Eastern Region (NER) of India lies between 25002'E - 26007'N latitude and 89049'E and 92050' E longitude. The geographical area of the state is 22,429 sq. Km with a total population of 29, 64,007 (Census, 2011). It comprises of three hill regions namely Khasi Hills, Jaintia Hills and Garo Hills. Currently the state is divided into 11 districts i.e. Garo Hills (5 districts), Khasi Hills (4 districts) and Jaintia Hills (2 districts). Undulating topography dissected by numerous rivers and streams are the characteristic features of the state. The state is blessed with rich and diverse natural resources, both renewable and non-renewable. Major renewable resources include water, forest, a variety of flora and fauna etc. Important non-renewable resources present in Meghalaya are coal, limestone, granite, uranium, kaolin, clay, glass sand etc. Of these, mining of coal and limestone has been taking place at large scale. Mining and exploitation of minerals have provided opportunity for a variety of employment and livelihood options to the local people. Besides, it has also contributed towards industrial and economic development of the state. On the other hand, exploitation of rocks and minerals including limestone has affected the local environment at its various stages of mining, processing and utilisation. In this article an attempt has been made to review the available information on limestone mining and its environmental implications in Meghalaya.

Geology of Limestone in Meghalaya

Geologically, the state of Meghalaya comprises of five different rock units namely: Pre-Cambrian gneissic complex with acid and basic intrusive, Shillong Group of rocks, Lower Gondwana rocks, Sylhet Traps and Cretaceous– Tertiary sedimentary rocks.

Limestone is distributed predominantly in the southern fringe of Meghalaya plateau and falls under the rocks formation units of Cretaceous–Tertiary sedimentary rock, which is divided into three groups i.e. the Khasi group, the Jaintia Group and the Garo group. The Jaintia Group is further sub divided into three formations which include the Longpar (lower), the Shella (middle) and the Kopili (upper) formations. The Shella formation is further subdivided into six members: the upper Sylhet Limestone (Prang limestone), upper Sylhet sandstone (Narpuh Sandstone), middle Sylhet Limestone (Umlatdoh limestone), middle Sylhet sandstone (Lakadong sandstone), lower Sylhet Limestone (Lakadong limestone) and lower Sylhet sandstone. The limestone deposited in Jaintia Hills possesses all the above three members of Sylhet limestone with alternating bands of limestone and sandstone. However, the limestone deposit in Cherrapunjee belongs to the lower Sylhet member (Lakadong limestone) of Shella formation consisting of limestone layers in the upper part of the hill and dolomite in the lower portion. Thus, the limestone rocks found in Meghalaya belong to the Shella formations of the Jaintia Group of Cretaceous – Tertiary sedimentary rocks of Eocene geological age (Sarma, 2003; DMR Profile, 2016).

Limestone Reserves in Meghalaya

Next to coal, limestone is the most abundantly found and extracted mineral in Meghalaya. Various grades and extent of limestone rocks are found in the southern fringe of the state extending for about 200 Km from Jaintia Hills in the east to Garo Hills in the west. According to Tripathi et al. (1996), the maximum limestone reserve in Meghalaya is reported in Jaintia Hills (55%), followed by Khasi Hills (38%) and Garo Hills (7%). Quality of limestone deposited in Meghalaya varies from cement to chemical grade in nature. In the Indian Mineral Yearbook (2012), it is reported that Meghalaya possesses about 9% of the country's total limestone reserve. However, as per the present status of cement grade limestone reserve report (2014), India possesses about 123,829.64 million tonnes of cement grade limestone. Out of which, about 14959 million tonnes (i.e. 12% of the country reserve) of limestone is present in Meghalaya. The geographical distribution of limestone in Meghalaya is depicted in Figure 1. It is mainly distributed in the districts of East Jaintia Hills, West Jaintia Hills, East Khasi Hills, West Khasi Hills and South Garo Hills.

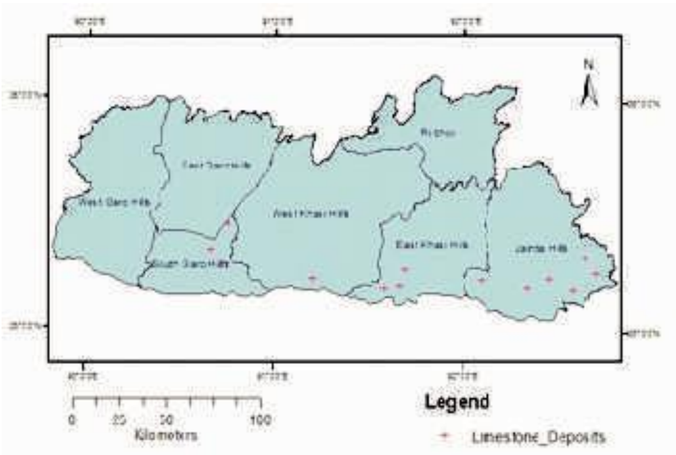

Fig. 1. Map showing distribution of limestone deposits in Meghalaya

Chemical Composition of Limestone

Limestone rocks are sedimentary in origin and classified as non-metallic mineral with inorganic origin in nature. The two most important constituents of limestone are calcite (calcium carbonate, CaCO3) and dolomite. Limestone often contain small amount of impurities such as magnesium, iron, manganese and lead. Dolomite is a carbonate of calcium and magnesium [CaMg(CO3)2]. Limestone is used in a wide range of industries. It has been utilised by man for thousands of years. However, it is a primary ingredient and raw material for cement manufacturing industries. Besides, it has many uses ranging from building material to white paints and fillers. It is also used as a chemical feedstock for the production of lime having numerous uses.

The limestone found in different parts of Meghalaya varies in chemical composition to some extent and thus differs in quality ranging from cement to chemical grade in nature. Generally, the CaO content of limestone found in Meghalaya is 53% (Kharkongor and Dutta, 2014). The chemical composition of various types of limestone found in Meghalaya is presented in Table 1.

Table 1 . Chemical composition of limestone rocks at different locations in Meghalaya

Major chemical compounds in %	Jaintia Hills					
	Lakadong	**Lumshnong**	**Nongkhlieh**	**Nongtalang**	**Sutnga**	**Syndai**
CaO	42.27-53.89	40.69-54.67	40.46-53.88	46.33	48.75-53.09	42.00-49.60
MgO	1.25-5.58	0.20-11.55	0.36-7.12	3.51	0.72 - 3.41	0.56 - 2.07
SiO_2	0.14-3.12	0.04-17.20	0.16-10.00	-	-	-
Fe_2O_3	0.26-1.59	0.04---3.87	0.07-4.91	-	-	1.73 - 2.31
Al_2O_3	0.22-2.61	0.05-5.71	0.16-6.37	-	-	-
R_2O_3	-	-	-	-	0.48 - 5.40	-
Al	-	-	-	9.07	1.08 - 3.78	6.11-13.90
	East Khasi Hills					
	Cherrapunjee	**Komorrah**	**Laitryngew**	**Mawlong-Ishamati**	**Shella**	
CaO	44.33-53.53	51.97-54.95	52.02-54.41	51.91-53.04	48.15-53.98	
MgO	0.33-4.21	0.76-2.98	0.15-2.25	0.43 - 4.76	0.72-6.85	
SiO_2	-	0.46-1.90	-	0.56 - 2.78	0.38-5.20	
Fe_2O_3	-	0.28-1.11	-	0.38 - 0.48	0.28-1.72	
Al_2O_3	-	0.16-0.56	-	0.26 - 1.06	0.48-2.18	
R_2O_3	0.31-2.17	-	-	-	-	
Al	1.43-12.39	-	3.00	-	-	

SO_3	-	-	-	-	Trace
P_2O_5	-	-	-	-	Trace
Na_2O	-	-	-	-	Upto 0.25
K_2O	-	-	-	-	Upto 0.25
	West Khasi Hills		**West Garo Hills**		
	Borsora		**Darrang-Era-Aning**		**Siju-Artheka**
CaO	41.86-53.32		38.00-51.35		46.90
MgO	0.48-6.10		0.55-4.04		1.72
SiO_2	0.36-4.52		0.66-6.61		-
Fe_2O_3	0.64-5.78		0.43-5.28		0.47
Al_2O_3	1.14-6.55		0.24-27.05		2.69

History of Limestone Mining and Cement Plants establishment in Meghalaya

The history of limestone mining in Khasi Hills of Meghalaya seems very old. As per the Assam District Gazetteers published in 1906, limestone quarrying and trading in Khasi Hills have existed as early as in eighteenth century and it was a lucrative business to the people of Sylhet in Bangladesh and Khasi Hills of Meghalaya. From the earliest days of British rule, it is described that the lime quarries were situated all along the southern face of the Khasi Hills. Limestone was mostly used to make lime by burning it all along the banks of the Surma River. It was also reported that lime transportation from Khasi Hills to Sylhet was done during the rainy seasons by using the natural mode of transportation (i.e. through river) using a flat bottom canoe. This attracted a large number of Europeans who largely controlled the limestone mining, production and trading of lime in this part of India (Allen, 1906). Thus, limestone mining in Meghalaya is taking place for long time, however earlier it was small scale and for local uses only mainly for the production of edible lime.

Later, limestone was used for the production of cement after establishment of cement manufacturing industries in Meghalaya. The Mawmluh-Cherra Cements Limited (MCCL) was the first cement manufacturing unit in the state. It was originally established by some unknown industrialists in Cherrapunjee in 1955 under the banner name of Assam Cements Limited. The company was later acquired by the Government of Assam in 1964 and thereafter by the Government of Meghalaya in 1974 (Dolloi, 1992). This indicates that large scale mining of limestone in Cherrapunjee for the production of Cement started quite early. Later, the Lafarge Umiam Mining Pvt. Ltd., (LUMPL) began extensive limestone mining in Shella-Nongtrai area of East Khasi Hills of Meghalaya for its utilisation in Chhatak, Bangladesh by Lafarge Surma Cement Ltd., (LSC). The limestone mined form Meghalaya is transported to Bangladesh via a 17 Km long cross border Conveyer belt. This activity has been performed in the area since 2005. The LSC start producing and selling cement from 2006. However, mining of limestone was halt in 2007 by the Supreme Court of India in this area due to the pending environmental clearance from the court. However, later in 2011 mining in the area was resumed.

The origin of limestone mining in Jaintia Hills of Meghalaya is not very well documented. The Jaintia Cement Limited was the first private cement manufacturing plant established in Sutnga Village in 1986. Extensive mining of limestone in Jaintia Hills, Meghalaya started after 2004 after establishment of Cement Manufacturing Company Limited (Star Cement) in Lumshnong and then followed by other privately owned cement manufacturing units in the area. However, utilisation of limestone in Garo Hills for cement production started in 1991. Presently, more than a dozen of cement manufacturing plants are in operation in the state.

METHOD OF MINING

Limestone extraction in Meghalaya is carried out by open cast method of mining. It is taking place at both large scale and small scale levels. The large scale extraction of limestone is taking place in Jaintia Hills mainly for the manufacturing of cement. While both large scale and small scale mining are in practice in

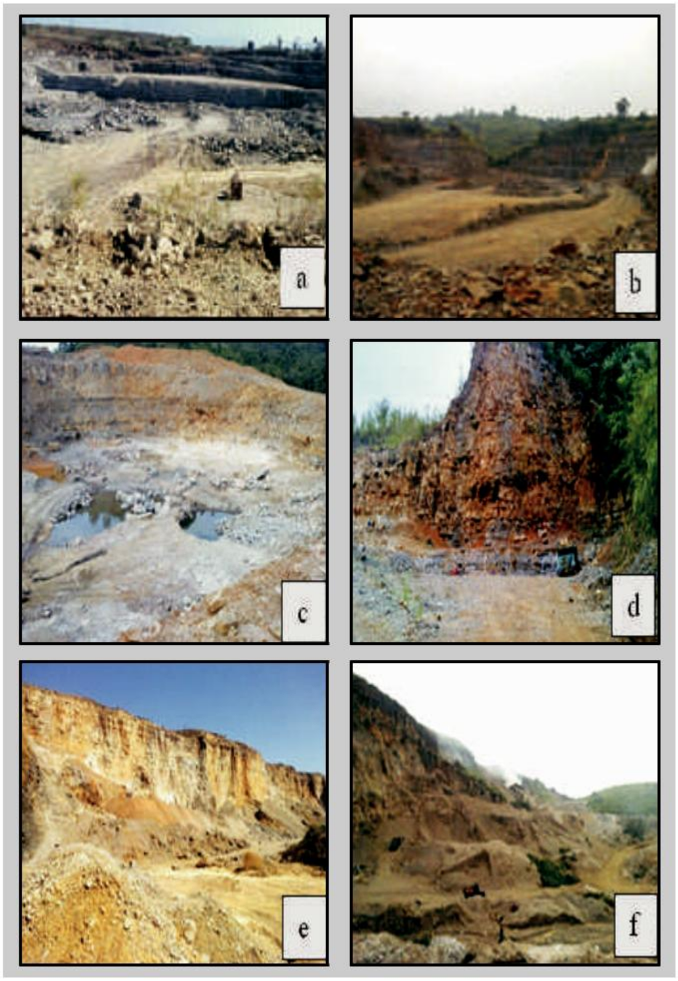

Fig. 2. Photographs showing open cast mining of limestone done by (a, b) cement companies; (c, d) locals in Jaintia Hills; (e, f) ASM limestone mining in Sohra, Meghalaya.

Sohra, East Khasi Hills (EKH) for production of cement, quicklime and edible lime.

The mining in Jaintia Hills is mostly done by cement industries. However, due to unique land holding system in Meghalaya, mining of limestone is also carried out by individual land owners. The mining process carried out by the cement industries is efficient being mechanical using heavy machinery for excavation. On the other hand, extraction by individual land owners is semi-mechanical and slow. Generally, extraction of limestone involves mechanical removal of overburden (using bulldozers), manual drilling the blast holes, blasting of rocks, manual shattering (sizing) of the limestone rock and then finally loading and transportation of limestone to the cement plants. Figure 2 shows different types of open cast mining of limestone in Meghalaya.

In Sohra (Cherrapunjee), limestone is being extracted both at large and small scale levels. The small scale extraction of limestone is done manually by individuals using minimal machinery and thus categorised as Artisanal and Small Scale mining (ASM). The extraction of limestone from the hillocks in Sohra (EKH) is carried out by several land owners sharing the entire Mawmluh hills. The limestone beds are drilled for blast holes using drilling machines, after which the rocks undergo blasting. The limestone rocks undergo manual sizing, so as to obtain a rock pieces of suitable size for easy transportation and processing in small vertical kilns. Mining is carried out by the people who are directly involved in the production of quicklime and edible lime. The processed lime is exported to the paper industry in the neighbouring states. The processed lime is also used for whitewashing of houses and walls. Other by-products (pulverised form of lime) obtained in the process of production of lime at ASM levels are used as soil conditioner in agricultural fields. Mining of limestone in Meghalaya is also done for other minor uses such as construction of temporary roadbed to the quarrying sites, cement plants and adjacent locality; house construction etc. Large scale mining is also done in Sohra, (EKH) by adopting mechanical methods for production of cement but by MCCL.

Cement Plants in Meghalaya

In last decade a number of cement plants were established in Meghalaya with maximum numbers found in Jaintia Hills alone. Presently, the cement plants are the main consumers of limestone rocks found in the state. The cement manufactured in Meghalaya is utilized in the state as well as transported to other states of the country. A list of cement plants operating in Meghalaya is given in Table 2.

Limestone Mining Leases in Meghalaya

In recent years, Government of Meghalaya has also granted limestone mining leases to several companies for mining of limestone, its utilisation and ultimately

Table 2. List of Major Cement Plants operating in Meghalaya

Sl. No	Company Name	Brand Name	Group	Location/Village (District)
1		Adhunik Cement	-	Thangskai (EJH)
2	ited	Amrit Cement	Amrit Group	Umlaper (EJH)
3	mpany Limited	Star Cement	Shyam Group	Lumshnong (EJH)
12	Cosmo Cement Ltd.	Cosmo Cement	-	Nongkhlieh (EJH)
13		Goldstone Cement	-	(EJH)
4	ted	Max Cement	GNG Group	Nongsning (EJH)
5	ed	Taj Cement	-	Mynkree (EJH)
6		Jaintia Cement	-	Sutnga (EJH)
7		Best Cement	Ud Group	Wahiajer (EJH)
8	Mawmluh-	Mawmluh-Cherra Cement	PSU	Mawmluh (EKH)
9	d	Topcem	Prithvi Group	Thangskai (EJH)
10		Magic cement	RNB Group	Barapani (Ri-Bhoi)
11	Virgo Cement Ltd.	Virgo Cement	-	Damas (EGH)

NB: EJH- - - East Khasi Hill

for manufacturing of cement. A list of mining leases granted to different companies operating in Meghalaya is given in Table 3. In addition to leases granted by the government, mining of limestone is rampant because of the unique land ownership in the state. Hence, mining in Meghalaya is predominantly in private hands. The extraction/mining of the rocks and minerals is carried out by the individual land owners in whatever way they deem fit and profitable. In most cases, the method of mining carried out was found unscientific, disruptive and degrading to the environment. Lack of reclamation responsibility and stringent regulated mining procedure further magnify the consequences of mining in Meghalaya.

Environmental Impact of Limestone Mining

Exploitation of rocks and minerals affect environment at its various stages of mining, processing and utilisation irrespective of its scale of mining. Denudation of forest, water depletion, pollution of water, soil and air, depletion of natural flora and fauna, reduction in biodiversity, erosion of soil, instability of soil and rock masses, changes in landscape and degradation of agriculture land are some of the conspicuous environmental implications of mining. The severity of environmental problems depends on the extent of mining and ecological sensitivity of the mining site. Both terrestrial and aquatic ecosystems are affected and the effects could extend beyond the boundaries of the mining area and be for a long term. Nartey et al. (2012) also reported that limestone quarrying in the Manya Krobo District of Ghana do have some negative effects on the environment. Impacts includes lowering of water tables, habitat destruction, encroachment of waste into agricultural land, destruction of buildings due to cracks, pollution of rivers, loss of biodiversity, destruction of crops, unclean rain water harvested from roofs and health related problems include inhalation of dust resulting in respiratory tract infections.

Table 3. Limestone mining leases granted by Government of Meghalaya

Sl. No	District	Name of Lessee	Location	Lease Period (Years)	Area in Hectare	Year Granted
1		Mawmluh Cherra Cement Ltd.	Mawmluh	20	139.67	2001
		Mining Co.	Komorrah	20	240.55	2003
		Pvt. Ltd	Nongtrai	30	100	2001
		Son	Ichamati Mawkhlain	20	4.56	2006
2	Jaintia Hills	Ltd.	Mootang Thangskai Block -1	20	4.9	2009
			Block -2	20	4.9	2009
			Block -4	20	4.9	NA
		M/S JUD Cement LTD	Wahiajer Narpuh	30	4.76	2009
		Co. Ltd	Lumshnong	20	4.96	2005
				20	4.7	2006
				20	4.85	2006
			Moiong, Chichruphi	20	4.8	2007
			Khliehjri, Thangskai	20	4.9	2006
3	West Khasi Hills	Anderson Mineral Pvt. Ltd	Lalghat Cherragoan	20	60	2007

Source: Directorate of Mineral Resources Portal, Government of Meghalaya (2016)

Scientific studies on impact of coal and limestone mining on different aspects of the environment have been done in both Khasi and Jaintia Hills regions of Meghalaya. Water quality deterioration (Swer and Singh, 2003); reduction in aquatic biodiversity (Swer and Singh, 2004; Mylliemngap and Ramanujam, 2011); diminishing plant diversity due to change in land use land cover (LULC) (Sarma and Kushwaha 2005; Sarma et al, 2010); forest cover changes (Lele and Joshi, 2009; Somendro and Singh, 2015) and degradation in agriculture field and its productivity (Gupta et al, 2002) due to coal mining have been extensively studied in Meghalaya. Recently, Chabukdhara and Singh (2016) reviewed the environmental issues of coal mining in northeast India. Similarly, impact of limestone mining and its processing for cement manufacturing has been investigated with reference to general environment and LULC change (Chakraborty and Sudhakar, 2014; Somendro and Singh, 2015) and water and soil quality (Lamare and Singh, 2014, 2015 and 2016a, b).

The vital ecological issues related to mining of limestone rocks are discussed below and various environmental problems observed as the results of limestone mining in Meghalaya are shown in Figure 3.

Changes in Land Use and Land Cover (LULC)

Geographic information system (GIS) combined with remote sensing (RS) has been widely used as a powerful and cost-effective tool for detecting and analyzing the spatio-temporal changes in LULC. In Meghalaya, Chakraborty and Sudhakar (2014) analyzed LULC changes in Jaintia Hills to focus the impact of limestone mining and cement manufacturing activities leading to the loss of forest cover during 2005 and 2011.

They observed striking changes in LULC which were implicated with limestone mining and expansion of the cement manufacturing units. The conversion of

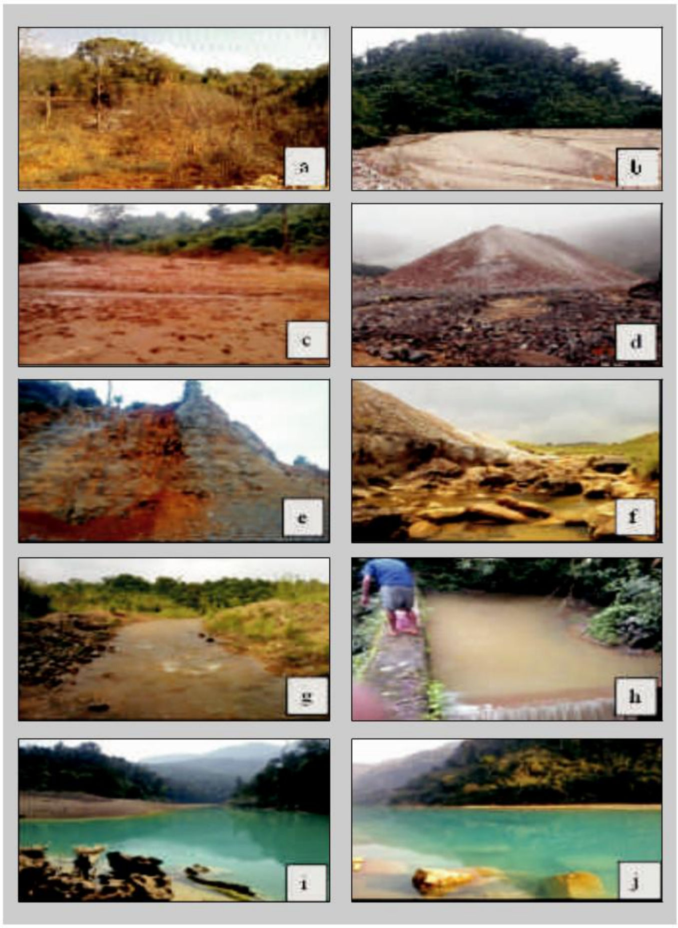

Fig. 3. Photographs showing (a) – Loss of forest cover; (b) – Creation of waste land by siltation; (c) - Encroachment of overburden into the forest area; (d) – ASM waste disposal forming a hill of lime waste dumping area; (e) – removal of top soil and landscape deterioration; (f) – encroachment of ASM waste into the nearby local streams; (g) - intrusion of mine waste such as rocks, pebbles and sand into the nearby streams; and (h) - local streams showing high turbidity due to its location near the cement plants; (i, j) - Blue colour of water of Lukha River during winter months.

forest area into non-forest area was observed. The total loss of forest in the area was found to be around 1265.36 ha from 2005 to 2011 within a radius of 5 km. They suggested for immediate necessary steps to control conversion of forest land into non-forest land. It is also known that forest depletion and land degradation have inevitable associations with extensive loss of habitat and biodiversity. Forest depletion is also intimately linked with loss of top layer of fertile soil and productivity. Recently, LULC was analyzed by Somendro and Singh (2015) in Jaintia Hills, Meghalaya during 1987 to 1999 and 1999 to 2013.

The study reported loss of forest cover and change in forest categories caused by various human activities such as mining of coal and limestone, industrial expansion, infrastructural development and built up area etc.

Further, a study covering north eastern region (NER) using satellite data was carried out during 1972 to1999 by Lele and Joshi (2009) to analyse the change in forest cover. They reported highest changes in forest cover in Meghalaya, Nagaland and Tripura. Reduction of forest cover in Meghalaya was attributed to extensive mining and shifting cultivation. Sarma and Kushwaha (2005) investigated the impact of mining on land use/land cover in Jaintia Hills during 1975–2007 and revealed extensive loss of vegetation and forest cover due to mining.

Similar studies have also been done in other parts of the country. Rajwar (1982) reported that unscientific and uncontrolled method of limestone mining in Mussoorie mountains have caused various adverse environmental impacts on the surrounding area leaving the region appeared scarred with irregular patches, loss of vegetation cover, emergence and growth of xerophytes, instability of the mountains and aesthetic degradation of the area. Likewise, limestone mining in Dehradun district was also reported to have consequences on forest cover. Depletion in plant diversity due to the stripping off, random digging and quarrying in the hills has also been reported (Sikka et al., 1984).

Degradation of Soil

Mining of rocks and mineral has an irreversible impact on soil both in terms of its quantity and quality. Excavation of land leads to loss of top fertile soil and alters the quality of soil in surrounding areas in terms of its physical, chemical and microbiological properties (Ghose, 2004). Removal of top soils is the basic operations involved in mining processes resulting into elimination of seed bank and root stocks (Parrotta *et al.*, 1997), depletion of organic matter and nutrient contents (Akala and Lal, 2001; Panwar, 1999), modification of soil texture and structure (Grunwald *et al.*, 1988; Norland, 1993) and drastic deterioration in quality of soil (Adewole and Adesina, 2011).

Literature review revealed limited studies on impact of limestone mining on soil quality. Lamare and Singh (2015) reported land degradation and alteration of landscape topography by dumping of overburden/spoils and lime waste material due to artisanal and small scale limestone mining in Meghalaya. Further, excavation of limestone resulted in removal of fertile top soil and generation of spoil and overburden deteriorated the aesthetic beauty of the proximate landscape.

Sharma *et al.* (2013) emphasised that continuous mining of limestone in Solan District of Himachal Pradesh has induced dilapidation of the land environment of the area and deterioration of soil quality. This is chiefly due to the negative effects of mining activities such as deforestation, mining, and dumping of mining waste etc. Intensive quarrying of limestone in Mussoorie Mountains was reported to have led to loss of top soil and consequently acceleration of soil erosion in the area resulting into siltation of nearby rivers and streams and agricultural fields (Rajwar, 1982). Similarly, the soil regime of Madukkarai Limestone mine was also reported to be affected either directly or indirectly indicating low nutrient content compared to the soil in agricultural areas (Ravichandran *et al.*, 2009). Hanief et al. 2007 reported alteration in soil texture due to limestone mining in Sirmaur district of Himachal Pradesh. They found high percentage of sand and drastically low percentage of silt and clay in the mining affected soil. Sulphate content in the soil near limestone mines and cement plants in Rajasthan was reported to be high (GSI, 2009).

Etim and Adie (2012) reported that mining of limestone supported leaching of metals from the top soil into the surrounding area. Soil samples were found to range from uncontaminated to moderately contaminated categories in terms of heavy metal contamination coupled with low organic matter content. In contrast to these findings, Afeni et al. (2012) reported no significant adverse impact was observed on quality of soil in Nigeria, due to limestone exploitation.

Changes in Water Quality

Mining is known to affect water resources severely both in terms of its quantity and quality. Changes in water levels and flow, availability of potable and irrigation water, changes in sediment flow and deposition, degradation of water quality, reduction and degradation of habitat of aquatic flora and fauna and decrease in abundance and diversity of aquatic species are some of the adverse impacts of mining. Miller (1999) pointed out that water resources, undoubtedly are being polluted, diverted and disturbed from their natural conditions as a result of mining activity. As any other mining, the mining of limestone rocks is also reported to cause alteration in the quality of surface water and shallow groundwater (Naja *et al*. 2010). Iwanoff (2006) found high content of calcium, bicarbonates, sodium and chloride salts in the water of streams and rivers receiving a significant volume of mine water generated from open cast limestone mining areas in Northern Germany.

Deterioration of water quality due to limestone mining is also reported from India. Ravichandran *et al.* (2009) reported deterioration of water quality in Madukkarai limestone mine which was found responsible for exceeding the standard limit for water quality parameters like total dissolved solids, total hardness and chloride. However, no significant adverse impact of limestone mining on water quality was found in lower Himalayas (Prasad and Bose, 2001), Biramitrapur, Orissa (Mishra et al. 2004) and Vijayraghovgarh village, Madhya Pradesh (Ahmed *et al.*, 2007) and Chandrapur, Maharastra (Soni, 2007).

Assessment of water quality in limestone mining areas of Meghalaya was carried out in East Jaintia Hills (Lamare and Singh, 2014, 2016a, b) and East Khasi Hills (Lamare and Singh, 2015). In East Jaintia Hills, water samples of streams near limestone mining and cement plants were analysed. It was found that both limestone mining and cement plants have negative impact on the physicochemical characteristic of water of the area. Study found elevated levels of pH, conductivity, dissolve solids, hardness, calcium and sulphate in affected streams. It was also reported that Cement plants have contributed more towards water quality degradation than the limestone mining in East Jaintia Hills, Meghalaya.

Further, seasonal variation in water quality of Lukha River (Wah Lukha), a major river in East Jaintia Hills, Meghalaya was reported (Lamare and Singh, 2016b). For last 7-8 years water of the river turns deep blue in appearance during winter months. Activities such as mining of limestone and coal, manufacturing of cement, deforestation etc. occurring in the catchment were found responsible for seasonal changes in water quality of Lukha River. Acid mine drainage (AMD) from coal mining areas and powdery sediment, most likely originating from cement plants were suspected causing precipitation of aluminum and such other compounds which give deep blue appearance to water colour due to scattering of light. Physicochemical analysis revealed that river water possesses low pH and high electrical conductivity, turbidity, total solids and high concentration of calcium and sulfate.

Impact of Artisanal and Small Scale Mining (ASM) of limestone rocks in Sohra, Khasi Hills, Meghalaya was found to be localized near the limestone mining area (Lamare and Singh, 2015). High pH, EC and sulfate values were found remarkably above the standard range of water quality and recognized as the factors responsible for deterioration of water quality. Based on water quality index analysis, water at some locations was found not fit for drinking and other domestic uses throughout the year. CGWB (2012) also reported that coal mining; limestone quarrying and cement factories are the main anthropogenic activities causing problems to the environment of Meghalaya and in particular, chiefly the water bodies.

Impact on Air Quality

The main issue with mining in relation to air quality is generation of dust particles (Ghose and Majee, 2000). In mining or quarrying, different activities taking place are known to have an impact on air quality. Long term exposures to various air pollutants have significant health related problems (Sunyer, 2001).

Relatively, less work has been done on air pollution in relation to limestone mining. Rajwar (1983) found that the limestone quarrying elevates dust concentration and consequently affects physiology of plants. In addition, health related problems were reported by Mishra *et al.* (2004) as a result of limestone mining.

Activities involved during limestone extraction like drilling, blasting, loading and transportation generate dust into the surrounding area causing air pollution mainly suspended particulate matter (SPM). The gaseous pollutant released into the air are attributed by the motorized machine involved during the entire processes i.e. bulldozer, drilling machines, dumper and transportation vehicles. No data is available to on air quality of the limestone mining areas of Meghalaya. But, wide spread limestone mining and presence of large number of cement plants in Meghalaya are likely to have significant impact on air quality of the area.

Noise and Vibrations Problems

Extraction of limestone involves activities like drilling of blast holes, blasting of rock beds using explosives and transportation. These activities generate hefty and annoying noise pollution to the inhabitants and likely to have an adverse health impacts. In addition, multiple undesirable effects such as geological displacement and destabilisation of the area, drying up of spring water, decrease of water table, weakening of the rocks formation leading to slopes failures and increase probability of landslides. No information is available on noise pollution in limestone mining areas of Meghalaya.

Water Scarcity

Region with Karst topography are reported to have problems of water scarcity due to absence or lack of surface streams and availability of groundwater at a greater depth (Legard, 1973). In Meghalaya, only a few surface water bodies are present in limestone deposit areas. Some water bodies are found above ground for certain distances and then they disappear due to flowing underground and then again emerge at some point somewhere else. Such phenomena lead to water scarcity in the area. Mining of limestone and establishment of cement plants in the region have further aggravated the water scarcity in the area. The small natural streams near the mining vicinity are seen to have been deviated or covered with rocks, gravels, pebbles and sand. Excessive silting in all water bodies was also found in the area. Water bodies near the cement plants were found contaminated and water is not fit for human consumption (Lamare and Singh, 2014, 2016a).

Based on the field observation and feedback received from the local inhabitants, it was found that area is facing the problem of water scarcity particularly in winter months. The main causes are drying up of water sources and their contamination. However, in some villages due to limited access to portable drinking water, people have no choice but to use the polluted water for drinking and other domestic purposes. Many perennial streams and rivulets, in recent years have turned seasonal.

Other concomitant Problems

In East Jaintia Hills, Meghalaya various other concomitant problems were viewed due to the limestone mining and cement plants operating in the area. This area was formerly known for orange cultivation and production. However, due to land use land cover changes taking place in the area many orchards of oranges were found destroyed. Further, it was found that due to unknown reasons the orange trees in this area no longer bear healthy flowers and fruits and thus many farmers have stopped orange cultivation.

People residing in the hilly areas have the practice of harvesting rain water for drinking purposes. However, after the establishment of cement plants in the area, this practice has declined drastically due to the daily deposition of dust on the roof top causing the contamination of collected water. Decline of traditional agricultural practices to certain extent due to the quick revenue obtained from mining of limestone is another serious problem in the area. The locality situated adjacent to the cement plants experience deposition of thick dust throughout the year especially during dry season. Thus, the vegetation cover found here is no longer lush green and shows reduced plants growth. Cement dust falling on the soil are known to have effects such as change in the soil pH making it more alkaline and unfavourable for certain plants species and also causing leaf injury or death in plants due to blocking of light for photosynthesis (Darley, 1966; Lerman and Darley, 1975). Local inhabitants are also of the opinion that caves in this area possess very less number of fishes in recent years leading to drastic decline of cave fishing by the local people.

CONCLUSION

Based on above information it can be concluded that limestone mining in Meghalaya has impacted various components of environment and the life and livelihood of the local population. It is therefore attention of all concerned stakeholders; particularly the owners of mines and cement plants are drawn for proper management and conservation of the environment in order to halt further loss of forest cover and top soil and to prevent deterioration of water quality, soil degradation, air and noise pollution for the healthy environment and sustainable development of the region.

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