IMPACTS OF ACID MINE DRAINAGE ON SURFACE AND GROUND WATER: A CASE STUDY FROM MARGHERITA MINE SITE

A dissertation
submitted in the partial fulfillment of the requirement for the Award of the Degree of

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DECLARATION

I hereby declare that the work presented in this report entitled "**IMPACTS OF ACID MINE DRAINAGE ON SURFACE AND GROUND WATER: A CASE STUDY FROM MARGHERITA MINE SITE "** in the partial fulfillment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering submitted in the Department of Civil Engineering, Assam Engineering -College, Jalukbari, Guwahati-13 under Assam science and Technology University, is a real record of my work carried out in the said college for twelve months under the supervision of Dr Abinash Mahanta, Associate Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13, Assam.

Do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

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ABSTRACT

Mining activities in Northeastern Coal fields, Margherita Assam has resulted in degradation of soil and water pollution in the area. Acid generation and metal dissolution are the primary problems associated with pollution from mining activities. The acid mine drainage (AMD) is usually produced by the accelerated oxidation of iron pyrite, the most common sulfide mineral. The problem associated with acid mine drainage in that area is the presence of high levels of heavy metals and their disposal into the rivers without treatment. The persistence of this situation, therefore, poses a risk not only to the environment but also to the health and safety of the local population living near these sites. The study aimed to determine the presence of heavy metals such as arsenic, cadmium, chromium, copper, mercury, lead, zinc, manganese, aluminium, iron, and nickel and the effectiveness of lime neutralization in removing those heavy metals from the acid mine drainage. The paper indicates the result of the study showing high level of cadmium, lead and chromium. The result also shows a significant decrease in the contamination levels after neutralizing with lime.

Keywords: Acid mine drainage, iron pyrite, sulfide, heavy metals, lime neutralization

LIST OF TABLES

LIST OF FIGURES

CONTENTS

Title **Page No.**

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Coal plays an important role in energy generation, and 27% of the world's energy consumption originates from the incineration of coal (Bhuiyan et al. 2010). India is the third largest producer of coal with a provisional production of 893.08 million tons (MT) in 2022–2023 (Coal India Limited 2023), which accounts for 55% of the total energy generated in India (Ministry of Coal 2023). The Geological Survey of India estimated as on 1st April 2022 that the total reserves of coal are about 361.411 billion tons (BT), where 96.84% of the total reserves are shared by only seven states. Coal is the major source of energy which contributes 57.3% of the total energy supply (CEA 2018), and consumes about 8% of the total coal in the world (Yao et al. 2015). During the process of opencast and underground coal mining, a variety of rock types with different compositions are exposed to atmospheric conditions and undergo accelerated weathering (Reza et al. 2015). These waste materials typically contain variable amounts of sulphide minerals. After disposal, exposure to atmospheric oxygen and water results in sulphide oxidation and the formation of acid mine drainage (AMD) with variable pH, $S0_4^{2-}$and heavy metal content (Silva et al. 2011).

Acid mine drainage (AMD) is the result of the natural oxidation of sulphide minerals when exposed to the combined action of water and oxygen. It is considered as the worst environmental problem associated with mining (Kontopoulos 1998). AMD gives rise to several problems of environmental degradation - especially pollution of aqueous environment. The problems of AMD are intensely localised in the north eastern coal field of India, where ecology of the surrounding area is badly disrupted (Singh et al 1987).

Acid mine drainage offers favourable medium for existence of trace metals such as Fe, Ca, Mg, Al, Mn, Cu, Zn, Pb, etc. which are acid soluble and are leached from coal and associated strata during mining operations. Water quality deterioration due to acid mine drainage is of concern in the northeastern coalfield of India as the water in this area is severely polluted. The mine drainage water emanating from various collieries are highly acidic in character and contain high hardness, sulphate, total dissolved solid and iron coupled with low pH values which further results in contamination of trace (heavy) metals at significant levels. Trace metals are highly toxic and undesirable and are injurious to human health. These acidic waters are also typically hard in character because of iron sulphate content rather than common Ca-Mg bicarbonate type hardness. It leads to unacceptable water for drinking and recreational purpose (Singh et al 1985).

The drainages from the north eastern mines are found to be acidic with high sulphate ranging up to 1500 ppm and iron content rising-up to 40 ppm. The total sulphur in coal is up to 7% out of which 50-80% is non-reactive organically found sulphur. The acidity mainly arises from the oxidation of pyrites of coal (Narendra s. Rawat et al. 1982).

Environmental degradation caused by these acidic, iron rich effluent drainages has required assiduous efforts to find cost—effective abatement and treatment methods. The most commonly used method for treating acid mine drainage and removing trace (heavy) metals is neutralization. A typical system would include adding an alkaline reagent mixing, aerating, and removing the precipitate. Alkaline reagents that may be used are NH_3, Na_2C0_3, NaOH, lime and limestone. In most cases lime is used because of its lower cost and higher reactivity in conjunction with the effective removal of trace metals from acid mine drainages.

1.2 CHEMISTRY

1.2.1 Acid Generation and Metals Leaching

Acid generation and metals dissolution are the primary problems associated with pollution from mining activities. The chemistry of these processes appears fairly straightforward, but becomes complicated quickly as geochemistry and physical characteristics can vary greatly from site to site. Pyrite (FeS_2) is responsible for starting acid generation and metals dissolution in coal and hard rock sites alike. When pyrite is exposed to oxygen and water it will be oxidized, resulting in hydrogen ion release - acidity, sulphate ions, and soluble metal cations, equation 1. This oxidation process occurs in undisturbed rock but at a slow rate and the water is able to buffer the acid generated. Mining increases the exposed surface area of these sulphur-bearing rocks allowing for excess acid generation beyond the water's natural buffering capabilities.

$$2FeS_2\,(s) + 7O_2\,(aq) + 2H_2O \rightarrow 2Fe^{+2} + 4SO4^{-2} + 4H^{+}(1)$$

Further oxidation of Fe^{+2} (ferrous iron) to Fe^{+3} (ferric iron) occurs when sufficient oxygen is dissolved in the water or when the water is exposed to sufficient atmospheric oxygen.

$2Fe^{+2} + ½ O_2 + 2H^+ \rightarrow 2Fe^{+3} + H_2O$ (2)

Some acidity is consumed in this process; however, the stage is set for further hydrogen ion release that will surpass these benefits. Ferric iron can either precipitate as ochre ($Fe(OH)_3$ the red-orange precipitate seen in waters affected by acid mine drainage) or it can react directly with pyrite to produce more ferrous iron and acidity.

$2Fe^{+3} + 6H2O \leftrightarrow 2Fe(OH)_3 (s) + 6H^+$ (3)

$14Fe^{+3} + FeS_2 (s) + 8H_2O \rightarrow 2SO4^{-2} + 15Fe^{+2} + 16H^+$ (4)

When ferrous iron is produced as a result of equation 4 and sufficient dissolved oxygen is present the cycle of equations 2 & 3 is perpetuated. Without dissolved oxygen equation 4 will continue to completion and water will show elevated levels of ferrous iron.

Once the waters are sufficiently acidic, acidophilic bacteria - bacteria that thrive in low pH – are able to establish themselves. Microorganisms can play a significant role in accelerating the chemical reactions taking place in mine drainage situations. Thiobacillus ferrooxidans, a bacteria, is commonly referenced in this case. These bacteria catalyze the oxidation of ferrous iron, further perpetuating equations 2 through 4. Another microbe belonging to the Archaea kingdom, named Ferroplasma acidarmanus, has recently been discovered to also play a significant role in the production of acidity in mine waters.

Though not a major source of acidity, the generation of hydrogen ions when certain metals form precipitates, must be taken into account when considering treatment options.

$Al^{+3} + 3H_2O \leftrightarrow Al(OH)_3 + 3H^+$ (5)

$Fe^{+3} + 3H_2O \leftrightarrow Fe(OH)3 + 3H^+$ (see equation 3) (6)

$Fe^{+2} + 0.25 O_2(aq) + 2.5 H_2O \leftrightarrow Fe(OH)_3 + 2H^+$ (7)

$Mn^{+2} + 0.25 O_2(aq) + 2.5 H_2O \leftrightarrow Mn(OH)_3 + 2H^+$ (8)

Other metals commonly found in mine drainage waters exist because they are present in the rocks, similar to pyrite. For example, there are a variety of other metal sulphides that may release metal ions into solution, but may not generate acidity the reasons for this are not clear. Including:

$ZnS(s) + 2O_2\ (aq) \rightarrow Zn^{+2} + SO_4^{-2}$ (9)

$PbS(s) + 2O_2\ (aq) \rightarrow Pb^{+2} + SO_4^{-2}$ (10)

$NiS(s) + 2O_2(aq) \rightarrow Ni^{+2} + SO_4^{-2}$ (11)

$CdS(s) + 2O_2\ (aq) \rightarrow Cd^{+2} + SO_4^{-2}$ (12)

$CuS(s) + 2O_2\ (aq) \rightarrow Cu^{+2} + SO_4^{-2}$ (13)

$CuFeS_2(s) + 4O_2\ (aq) \rightarrow Cu^{+2} + Fe^{+2} + SO_4^{-2}$ (14)

Metals are naturally dissolved from weathering slowly over time. The dissolution process is sped up when the pH of the water strays from near-neutral, that is at either high or low pH - in the case of mine drainage low pH is the more plausible scenario.

1.2.2 Neutralization and Metals Removal

The ways by which metals precipitate have seemingly endless possibilities and are not always well understood. By far the most common application for reducing acidity and adding alkalinity is lime. There are many ways to treat mine drainage through enhanced natural processes which form the basis for passive treatments. There are many aerobic and anaerobic process that lead to metals precipitation that are commonly practiced. Though not complete the following information should provide some insight about the technologies that will be discussed shortly.

It is very important to gain control of the pH of the drainage because pH effects many things including the solubility of metals and the kinetics of the oxidation and hydrolysis processes. In addition, the relationship between pH and metal removal processes varies among metals and also between biotic and abiotic processes (EPA, Vol. 4)

Limestone (calcium carbonate), rich in calcite, increases the pH of water by consuming hydrogen ions and adding alkalinity through bicarbonate ions.

$CaCO_3 + 2H^+ = Ca^{+2} + H_2O + CO_2$ (15)

$CaCO_3 + H_2CO_3 = Ca^{+2} + 2HCO_3$ (16)

Once the pH of the acidic water has been raised metals can precipitate more easily to form hydroxides and oxyhydroxides, in some cases the pH alone will change the metal ion to an insoluble form, this is true in the case of aluminium.

Other commonly used alkaline agents are hydrated lime (calcium hydroxide), soda ash (sodium carbonate), caustic soda (sodium hydroxide), and in some cases ammonia.

The processes involving metals more common to coal mining regions (iron, aluminium, and manganese) are fairly well understood. The removal of iron is better understood than other metals common to drainage sites, which may be one of the reasons why passive treatments are more common in the East. Iron can form oxyhyroxides (FeOOH) or hydroxides (Fe(OH)3) under aerobic conditions or a sulphide solid under anaerobic conditions. Iron and manganese (Mn) precipitation processes are related in that the precipitations are sequential in aerobic conditions (EPA, Vol. 4). Iron oxidizes and precipitates more quickly than Mn because oxidized Mn solids are unstable in the presence of Fe+2 therefore the levels must be reduced significantly before Mn can be converted to stable solid precipitates (EPA, Vol. 4). Manganese under aerobic conditions can form an oxyhydroxide (MnOOH) and oxides (Mn_3O_4 and MnO_2) and in alkaline environments a carbonate ($MnCO_3$) (EPA, Vol. 4). Manganese sulphide is highly soluble and therefore highly unlikely to remain precipitated if it should form under anaerobic conditions (EPA, Vol. 4).

Aluminium is removed from waters by maintaining the pH between 5 and 8, where $Al(OH)_3$ is highly insoluble; the passage of mine water through highly oxidized or reduced environments has no effect on Al concentrations (EPA, Vol. 4).

Technologies designed to remove metals common to hard rock mining almost always involve the establishment of sulphate reducing bacteria (SRB), which can be difficult in cold climates. Sulphate reducing bacteria remove metals from solution as precipitates as a result of their survival. SRB reduce sulphate to soluble sulphide when provided with an organic carbon source, i.e. compost; as a result of this process acetate and bicarbonate ion are also produced. The soluble sulphide reacts with the dissolved metals to form insoluble metal sulphides, equation 18; the bicarbonate ions increase the pH and alkalinity of the water, equation 17. Bicarbonate also allows for the possible production of Zn, Cu, or Mn carbonates. Metals likely to form insoluble sulphide precipitates include: Cu, Zn, Cd, Pb, Ag, and Fe(II). These processes are summarized by the following reactions:

$SO_4^{2-} + 2CH_2\,O \longrightarrow H_2S + 2HCO_3$ (17)

$H_2S + M^{2+} \longrightarrow MS + 2H^+$ (18)

In addition to precipitation processes, metals can be removed from water through a variety of methods common to wetlands, and seen in technologies utilizing organic matter and/or vegetation:

1. Filtering suspended and colloidal material from the water
2. Uptake of contaminants into the roots and leaves of live plants
3. Adsorption or exchange of contaminants onto inorganic soil constituents, organic solids dead plant material or algal material –
4. Neutralization and precipitation of contaminants through the generation of HCO3 and NH3 by bacterial decay of organic matter.
5. Destruction or precipitation of chemicals in the anaerobic zone catalyzed by the activity of bacteria
6. Destruction or precipitation of contaminants in the aerobic zone catalyzed by the activity of bacteria.

1.3 PHYSIO-CHEMICAL TEST:

It is essential to test the water before it is used for drinking, domestic, agricultural, or industrial purposes. It is necessary to examine water using many physicochemical parameters. The selection of parameters for water testing depends entirely on the intended use of the water and the required level of quality and purity. Water does contain different types of floating, suspended, and microbiological as well as bacteriological impurities. Some physical tests should be performed to test its physical appearance such as temperature, pH, turbidity, TDS, etc., while chemical tests should be performed for its BOD, COD, dissolved oxygen, alkalinity, hardness, and other characteristics. Drinking water should pass these entire tests and it should contently require amount of mineral level.

1.4 HEAVY METAL TEST:

Heavy metals occur naturally in the Earth's crust. They are found and distributed in living tissues of an organism and in different components of the environment. However, at low concentrations, they possess no potential risk or hazard to any living organisms or the environment. Some heavy metals are arsenic (As), chromium (Cr), cadmium (Cd), nickel (Ni), zinc (Zn); lead (Pb), manganese (Mn), etc. The high levels of the metals produce an adverse effect on plants, animals, aquatic life, and as well as also on human health. Therefore, it is important to monitor and assess the level and degree of heavy metals in the environment.

1.5 BACKGROUND OF THE STUDY

The coal mining industry in Northeast India, particularly in states like Assam, Meghalaya, and Nagaland, has a significant historical and economic background. Coal mining in Northeast India began in the 19th century, with the first major discoveries in the Jaintia Hills of Meghalaya. British colonial interests fuelled the early development of the coal industry to support railways and other infrastructure. After India's independence in 1947, the coal mining sector continued to grow, though it faced challenges such as outdated mining techniques and regulatory hurdles. Meghalaya and Assam in northeast India contain 73 % of the total tertiary coal reserves. Nagaland and Arunachal Pradesh contribute 21 % and 6 % of the total tertiary coal reserves, respectively. India’s peak power demand is expected to reach 458GW by 2032, i.e. an 83% increase from 250GW in 2020. Therefore, there will be plans to push thermal power plant projects which leads to extraction of more coal from these areas.

1.6 OBJECTIVES OF THE STUDY

- The primary objective of the study is to find the concentration of heavy metals present in the samples.
- Comparative study of concentration of heavy metals between an existing coal field and an extinct coal field.
- The second objective is to reduce the concentration of heavy metals by the process of neutralization.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

To conduct any scientific study, a thorough understanding of the topic or place is essential. This can be achieved through an extensive literature review of noted researchers' work. Literature reviews, primarily involving secondary sources, help readers evaluate the strengths and weaknesses of existing information, forming a broad, scientifically sound concept. For the study on "Acid mine drainage" various researchers' literature was summarized to familiarize with established knowledge. Methods for literature: -review include analysing books, journals, thesis, reports, and papers. Digital sources like e-Libraries, and Google Scholar, have greatly simplified and enhanced the process of gaining and sharing knowledge. The major, work carried out by different researchers are summarized below:

2.2 REVIEW ON LITERATURE:

Singh et al. (1985) reported the problem of acid mine drainage in some coal mines in North Eastern India, which contains high levels of trace elements that are undesirable for drinking water. The study aimed to determine the effectiveness of lime neutralization in removing these trace metals from the acid mine drainage. The results show that lime neutralization was very effective in removing trace elements such as arsenic, cadmium, chromium, copper, mercury, lead, zinc, manganese, aluminium, iron, and nickel from the acidic mine water.

Rawat et al. (1985) examines the nature of acid mine drainage in the North Eastern Coalfield of India. The mine drainages are found to be acidic, with high sulphate and iron content. The acidity is primarily caused by the oxidation of pyrites in the coal. Microscopic analysis reveals the presence of both reactive and stable pyrites in the coal samples. Leaching studies indicate that the oxidation of reactive pyrites, followed by the dissolution of sulphate sulphur, is the main driver of the observed acidity, while organic sulphur does not play a significant role. The presence and activity of iron-oxidizing, sulphur-oxidizing, and iron-sulphur-oxidizing bacteria in the mine waters was confirmed, with Thiobacillus ferrooxidans identified as the dominant species. These bacteria were found to accelerate the leaching of sulphur from the coal.

Singh (1987) discusses the issue of acid mine drainage (AMD) and its impact on water quality deterioration in the northeastern coalfield of India. AMD from various coal mines in the region is highly acidic, containing high levels of hardness, sulphate, total dissolved solids, and iron, as well as toxic trace metals. This contamination of the aqueous environment severely disrupts the local ecology and has detrimental effects on aquatic life, mining equipment, and water supplies. The study presents the findings on the nature and extent of AMD-induced water quality issues in some of the northeastern coal mines of India.

Key Points

- Acid mine drainage (AMD) is a major environmental concern in the northeastern coalfield of India, leading to severe water pollution
- AMD from coal mines in the region is highly acidic, with high levels of hardness, sulphate, total dissolved solids, iron, and toxic trace metals
- The contaminated water is unsuitable for aquatic life, damages mining equipment, and increases the cost of water treatment for various supplies
- The study examines the impact of AMD on water quality deterioration in several coal mines in the northeastern region of India

Johnson et al. (2005) summarizes that acid mine drainage (AMD) is a significant environmental problem caused by the oxidation of sulphide minerals, particularly iron pyrite, in active and abandoned mines. This review discusses various options for remediating AMD, which can be divided into chemical and biological strategies. The key is to either prevent the formation of AMD at the source or to mitigate its impact through active or passive treatment systems. Source control measures aim to exclude oxygen and water from reacting with the sulphide minerals, while migration control options focus on neutralizing the acidity and removing metals from the AMD. Both abiotic and biological systems can be designed as active (requiring continuous inputs) or passive (requiring minimal maintenance) approaches. The review compares the strengths and weaknesses of these different remediation technologies and discusses the factors that influence the selection of an appropriate system.

Baruah et al. (2010) discusses the management of acid mine drainage (AMD) in Indian coal mines, particularly in the North-Eastern region. AMD is a major environmental concern in these mines due to the high sulphur content of the coal and the unscientific mining practices. The paper describes the mechanism of AMD formation, its impact on the environment, and various prevention and mitigation strategies. The key focus is on developing an Environmental Management Plan (EMP) for high-sulphur coal mines through laboratory simulation studies and identifying effective treatment options for the acidic effluents generated.

Bhuiyan et al. (2010) assessed the heavy metal pollution in agricultural soils affected by a coal mine in northern Bangladesh. The researchers found that the average concentrations of several heavy metals, including titanium, manganese, zinc, lead, arsenic, iron, rubidium, strontium, niobium, and zirconium, exceeded the world normal averages. In some cases, manganese, zinc, arsenic, and lead levels exceeded the toxic limits. Soil pollution assessment using enrichment factor, geo-accumulation index, and pollution load index revealed significant enrichment and accumulation of these metals, indicating inputs from mining activities. Multivariate statistical analyses suggested that manganese, zinc, lead, and titanium are derived from anthropogenic sources, particularly coal mining. The extreme proximal and distal parts of the coal mine-affected area were found to be heavily contaminated with maximum heavy metal levels.

Giri et al. (2014) reported that Coal mining in the Northeastern Coalfields of Margherita, Assam has resulted in significant ecological degradation in the area. The mining activities have led to the loss of forests and topsoil, acid mine drainage, and soil and water pollution. The acid mine drainage has caused physical, chemical, and biological degradation of the aquatic ecosystems, adversely affecting the soil environment and agricultural productivity in the region. Eco-restoration of the mine-degraded land is an urgent need to address this environmental challenge.

Yao et al. (2015) reported that coal fly ash is a complex and abundant industrial by-product generated from coal combustion in thermal power plants. If not properly disposed of, it can cause environmental pollution and hazards. However, there are various potential applications for coal fly ash, including use in soil amelioration, construction, ceramics, catalysis, environmental protection, depth separation, zeolite synthesis, and valuable metal recovery. This review provides a comprehensive overview of the global generation, physicochemical properties, and hazards of coal fly ash, as well as its current and potential applications. The review also discusses the mode of fly ash utilization in major countries like China, India, the US, and the EU, and identifies directions for future research.

Reza et al. (2015) investigated the spatial distribution and extent of heavy metal (Fe, Mn, Zn) pollution in agricultural soils affected by coal mining activities in the Ledo coal mining area of Tinsukia district, Assam, India. The researchers used geostatistical and multivariate analysis techniques to analyse soil samples collected from a 20 km2 area. The results showed high concentrations of Fe, Mn and Zn in the low-lying rice fields and near the coal mining site. Geostatistical analysis revealed the spatial dependence and distribution patterns of the heavy metals. Principal component analysis suggested that Fe was derived from anthropogenic sources like coal mining, while Mn and Zn had both lithogenic and anthropogenic origins.

Contreras et al. (2015) discusses the issue of acid mine drainage (AMD) in Chile, which is a major environmental problem caused by the mining industry. AMD is produced when sulphide-bearing materials are exposed to oxygen and water, leading to the release of toxic substances such as heavy metals. The paper describes the chemistry behind AMD formation and the scale of the problem, with estimates of the affected areas and cleanup costs in other countries. It highlights the need for effective remediation technologies to address this issue and ensure a sustainable mining industry in Chile.

Key Points

- Acid mine drainage (AMD) is a serious environmental problem associated with mining activities, particularly in Chile
- AMD is caused by the oxidation of sulphide minerals like pyrite, leading to the release of acidity, sulphates, and heavy metals
- The scale of the AMD problem is significant, with large areas and water bodies affected in countries like the USA and Canada
- Conventional treatment technologies for AMD are expensive, so bioremediation is presented as a more cost-effective and environmentally-friendly alternative
- Addressing the AMD issue is crucial for ensuring a sustainable future for the mining industry in Chile

Chabukdhara et al. (2015) provides an overview of the environmental issues associated with coal mining in northeast India. The region has significant deposits of sub-bituminous tertiary coal with unique physicochemical characteristics, including high sulphur, volatile matter, and vitrinite content, as well as low ash content. These characteristics lead to severe environmental impacts from mining and coal utilization. Key environmental challenges include large-scale landscape damage, soil erosion, loss of forest ecosystems and wildlife habitats, and air, water, and soil pollution. The paper reviews current research on various physical and chemical treatment approaches to address the high sulphur content and associated environmental issues of these coals. It highlights the need for adopting innovative clean technologies, effective control measures, and regulatory policies to enable the sustainable use of coal resources in the region.

Munawer (2017) in his review article discusses the human health and environmental impacts of coal combustion and post-combustion wastes. Coal is a major source of energy globally, but its combustion leads to the emission of various pollutants like COx, SOx, NOx, particulate matter, and heavy metals. These pollutants can have severe impacts on the environment and human health, including contributing to global warming, acid rain, respiratory diseases, cardiovascular problems, and cancer. The article provides an overview of the key pollutants and their effects, highlighting the need for further research on the cumulative health impacts and the development of better management protocols to address these issues.

Benidire et al. (2021) summarizes the environmental impacts of mining activities in Morocco, particularly the effects on soil properties around abandoned mine sites. The Moroccan mining industry is a major contributor to the country's economy, with phosphate rock being the most important mineral resource. However, mining operations can cause significant environmental damage, including landscape alterations, release of hazardous tailings, and pollution of air, water, and soil. The review focuses on case studies of several abandoned mines in Morocco, where the tailings with high acid-generating potential have led to severe soil contamination with toxic metals like cadmium, copper, lead, and zinc. This pollution continues to spread through the environment due to the lack of proper remediation of these mining lands, posing risks to the local population and ecosystems.

Saha et al. (2022) reported that acid-mine drainage (AMD) is a global environmental issue that arises from the mining of metals and minerals. AMD is generated when water comes into contact with sulphur-bearing minerals, leading to the formation of acidic, metal-rich wastewater. This wastewater can pollute water bodies, contaminate soils, and enter the food chain, posing risks to aquatic life and human health. The document discusses the characteristics of AMD, its environmental consequences, and the challenges in assessing the economic and environmental liabilities associated with it.

Marove et al. (2022) investigates the contamination of surface soils, river sediments, river water, and groundwater around coal mines in Moatize district, Tete province, Mozambique. The researchers used various water and soil/sediment pollution indices to assess the levels of contamination in the area. The results show that all water samples were "uncontaminated" to "moderately contaminated" with hazardous metals, with many values exceeding drinking water standards. Surface soils and sediments from the Moatize and Murrongoze Rivers were found to be "highly polluted". Leaching experiments suggest that hazardous elements from soils and sediments could pose serious ecological and health risks in the area.

Rouhani et al. (2023) in the paper provides an overview of soil pollution and remediation strategies in coal mining regions. Coal mining, both surface and underground, can have significant environmental impacts, including ecosystem losses, landscape alteration, soil destruction, and changes to surface and groundwater quality. Toxic compounds such as heavy metals, radioactive elements, polycyclic aromatic hydrocarbons (PAHs), and other organic contaminants are released into the environment, affecting ecosystems and human health. While modern mining practices have decreased environmental impacts, many sites are inadequately reclaimed and present long-lasting soil pollution problems. The review summarizes progress in understanding coal mining impacts on soil pollution, the potential risks of soil pollution, and different remediation strategies.

Chakrabortty et al. (2023) discusses the issue of soil pollution caused by coal mining activities in India. It highlights the significant environmental impact of opencast mining, which has become the dominant mode of coal extraction in the country. The review examines the deteriorating effects of coal mining on the physical, chemical, and biological characteristics of soil, including the release of trace metals and heavy metals.

It also presents various conventional and modern remediation techniques available to address soil contamination, such as soil replacement, thermal desorption, and bioremediation. However, the commercial application of these techniques has been limited due to inefficient technologies, lack of awareness, and high costs. The review emphasizes the potential of rock dust application as an emerging solution for soil remediation and remineralization in coal mining areas.

Chandra et al. (2023) discusses the role of modified biochar in the remediation of coal mining-impacted contaminated soil. It highlights the environmental impact of coal mining, including the release of heavy metals and acid mine drainage, and the challenges in restoring such contaminated sites. The review presents detailed information on the production and modification of biochar, as well as the mechanisms by which biochar and its composites can effectively immobilize and remove heavy metals from contaminated mine soil. The review also critically evaluates the efficacy of biochar-based remediation approaches using various case studies and data from previous research. The key conclusion is that the application of functionalized biochar composites can effectively manage and remediate heavy metal contaminated mine soil.

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 GENERAL:

To achieve the project's goal, pertinent laboratory experiments will be carried out according to Indian standard procedures and the corresponding IS codes. This chapter presents the test programs for the various laboratory tests that will be conducted as well as the related findings.

3.2 TEST PROGRAM

The phase of the complete program are as follows

1. Collection of water samples from different stations in the vicinity of the coal mine.

2. Preservation of the samples as per Indian standard.

3. Determination of physical and chemical properties of the samples.

4. Determination of heavy metal in the samples.

5. Use of lime neutralization method for removal of heavy metals.

6. Analysis of test results.

3.3 WATER SAMPLING STATIONS

Water samples are collected in the post monsoon season in the vicinity of the coal mine.

Table 3.1: Sampling stations with their latitude and longitude:

SL NO	STATIONS	LATITUDE	LONGITUDE
1.	Borgolai	27.2855699°N	95.7148379°E
2.	Tipong	27.3012°N	95.34397°E
3.	Ledo	27.291°N	95.6909°E

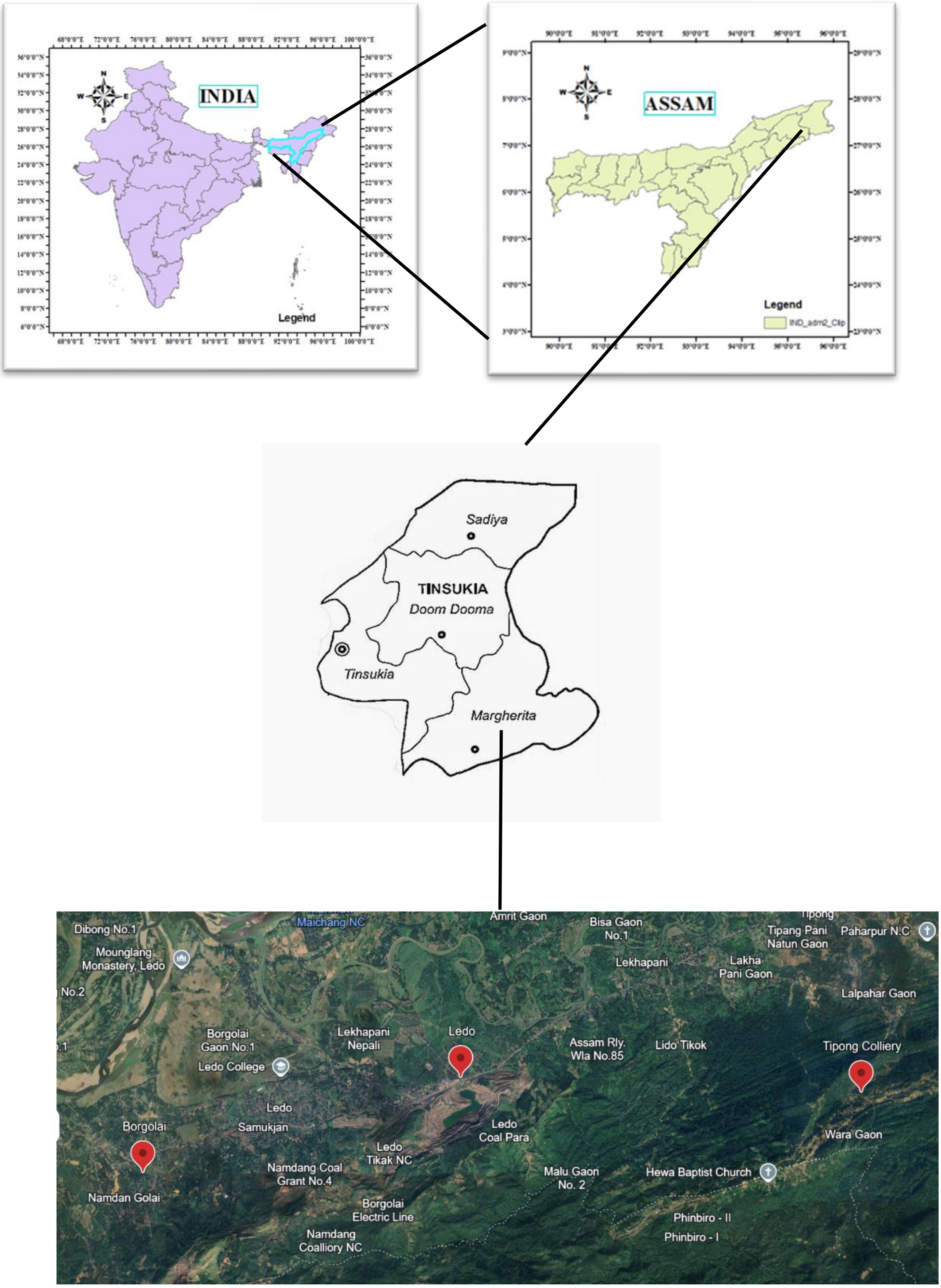

Fig 3.1: Sampling stations

Source: Google Earth

Fig 3.2: Sample collection from Borgolai

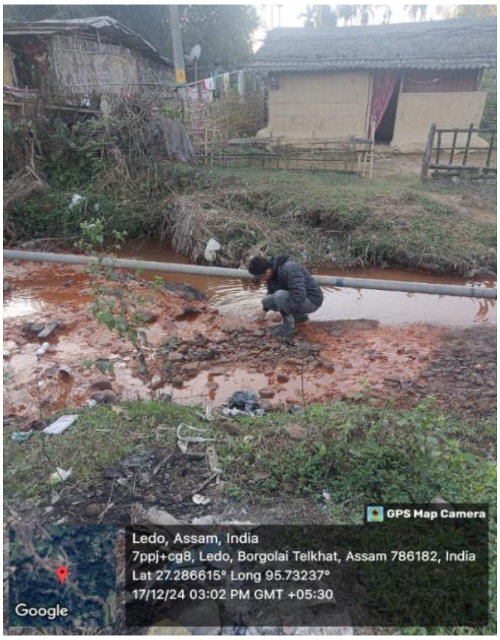

Fig 3.3: Sample collection from Ledo

Fig 3.4: Sample collection from Borgolai

Fig 3.5: Sample collection from Tipong

3.4 COLLECTION AND PREPARATION OF WATER SAMPLES:

A total of 5 water samples were collected from 5 different sampling stations including ground water and surface water. The samples were collected about 200-300 meters away from the mining site. The water sampling was manually performed and collected samples belong to grab samples. Tape (boring), hand pumps, and ring wells were used to collect groundwater samples. The sampling was done in 2-L polyethylene bottles. The method of sampling and collection are by standard methods for the examination of water [IS 3025 (part 1):1987].

All samples were collected, preserved, and stored for analysis as outlined in standard methods for the examination of water and wastewater. Water and wastewater sampling are done as per Indian standard IS 3025 (Part 1):1987.

As per IS 3025 (Part I): 1987 for water and wastewater sampling specific guidelines should be followed which are discussed below

1. Selection of the container or bottle is done in the following ways-

   - Glass containers— It should be cleaned with water and detergents to remove dust and packing material. They should then be cleaned with chromic acid-sulphuric acid mixed before being thoroughly rinsed with distilled water.
   - Polyethylene containers - It should be cleaned by filling them with acid or hydrochloric acid leaving for 1 to 2 days, followed by thorough rinsing with distilled or de-ionized water.
   - Sample Volume: - A two-litre sample is normally sufficient for a physicochemical Test.
   - Measures should be adopted in the following way from the place of sampling to the laboratory:
   - The sample should be collected in a leakproof glass or plastic container.
   - The sample should be transported in an ice box keeping the temperature around 4°C.
   - Undue jerking of the samples should be avoided as this may result in coagulation of the suspended matters.
   - Immediately after reaching the destination, the samples should be transferred to the refrigerator.

- A wax pencil may be used for writing details on the labels which should be protected from wetting.
- The sample bottles should be carefully providing the following information:
  a. Place of sampling,
  b. Time and date of sampling,
  c. Types of sampling and depth of sample,
  d. Purpose of sampling.

2. Sampling Location for groundwater -The sample has to be collected from borehole at a desired depth.

3.5 DETERMINATION OF PHYSCIO-CHEMICAL PROPERTIES:

The parameters for water quality characterization have been used within the permissible limits' prescribed by the Bureau of Indian Standards. These refer to domestic water supplies for drinking water. A few numbers of parameters have been studied in this work and these are mentioned below: pH, conductivity, turbidity, total dissolved solid, total hardness

Physical Parameters:

pH: The pH of a solution refers to hydrogen ion activity and is expressed as the negative logarithm of hydrogen ion concentration. The pH of the various samples is measured with the help of pH meter.

Turbidity: Turbidity in water is caused by the presence of suspended matter, such as clay, silt, colloidal organic particles, plankton, and other microscopic organisms. Turbidity is also caused by discharges of domestic and industrial wastewater containing soaps, detergent, etc. turbidity meter is used to measure the turbidity of the samples. The values are expressed in NTU.

Total Hardness: According to IS: 10500-2012, the desirable limit for water hardness is 200 and the permissible limit is 600 mg/l. Hardness in water can cause scale formation in utensils, hot water systems, and boilers, as well as soap scum. The primary sources of water are dissolved calcium and magnesium from soil and aquifer minerals containing limestone or dolomite. Hard water can be treated using softeners, ion exchangers, and reverse osmosis processes. The degree of hardness in drinking water is classified based on the equivalent CaC03 concentration as follows: soft (0-6mg/l), medium (60-120 mg/l), hard (120-180 mg/l), and very hard (greater than 180 mg/l).

Total Dissolve Solids: The difference between total solids and suspended solids is used to determine filterable solids by analysing the filtrate and following the same procedure. In a water sample, this also can be estimated through conductivity measurement. According to IS: 10500-2012, the acceptable limit for total solids is 500 mg/l, and the permissible limit is 2000 mg/l.

Arsenic: Arsenic is a heavy metal present in trace amounts, which is highly toxic even at very low concentrations, and causes serious physiological disorders. Arsenic tends to accumulate in body tissues to cause arsenosis. It is determined by a flame atomic absorption spectrometer.

Chromium: The chromium content of the sample is determined by atomic absorption spectrophotometry. For dissolved chromium the filtered sample is directly aspirated to the atomizer. For total recoverable chromium, HNO_{3-} H_2SO_4 digestion is to be carried out prior to aspiration of the sample. This method is applicable in the range from 0.2 to 10 mg/l of chromium. However, the concentration range will vary with the sensitivity of the instrument used.

Cadmium: Cadmium is a heavy metal with a high toxicity. Cadmium is toxic at very low exposure levels and has acute and chronic effects on health and environment. Cadmium is not degradable in nature and will thus, once released to the environment, stay in circulation. New releases add to the already existing deposits of cadmium in the environment.

Mercury: Mercury is a heavy metal that is well-known for its toxicity and environmental impact. It is a naturally occurring element found in the Earth's crust, and it exists in several forms, including elemental mercury (Hg), inorganic mercury compounds, and organic mercury compounds, such as methylmercury. Each form has different properties and levels of toxicity. Mercury is released into the environment through both natural and anthropogenic (human-made) sources. Natural sources include volcanic eruptions and the weathering of rocks. Human activities, such as coal burning, mining, and industrial processes, contribute significantly to mercury emissions.

Lead: Lead is highly toxic, and exposure can occur through inhalation, ingestion, or skin contact. The health effects of lead exposure are particularly concerning for vulnerable populations, such as children and pregnant women: Neurological Effects, Cardiovascular Effects and Reproductive Effects.

Zinc: Zinc is often classified as a heavy metal, although it is essential for human health and plays a crucial role in various biological processes. It is a naturally occurring element found in the Earth's crust and is the 24th most abundant element in nature. Zinc is essential for numerous physiological functions, but excessive exposure can lead to toxicity. While zinc is essential for health, excessive exposure can lead to toxicity, known as zinc poisoning.

Aluminium: Aluminium is a lightweight metal that is widely used in various industries due to its favourable properties, such as corrosion resistance, malleability, and conductivity. While aluminium is not typically classified as a heavy metal in the same way as lead, mercury, or cadmium, it is often included in discussions about heavy metals due to its potential health and environmental impacts when present in high concentrations.

Manganese: Manganese is a heavy metal that is essential for human health in trace amounts but can be toxic in excessive concentrations. Its role in various biological processes underscores its importance, while its potential for environmental contamination necessitates careful management. Understanding the balance between the benefits and risks associated with manganese is crucial for public health and environmental protection. Continued research, regulation, and responsible management of manganese use are essential to minimize its potential hazards while maximizing its benefits.

Iron: All kinds of water including groundwater have appreciable quantities of iron. Iron has a significance since a few microorganisms such as crenothrix, leptothrix, etc can utilize dissolved iron as an energy source and convert ferrous into ferric hydroxide. This gives appearance to the waters. Although iron has little concern as a health hazard, but is still considered as a nuisance in excessive quantities is determined by flame atomic absorption spectrometer.

3.6 DETERMINATION OF HEAVY METALS:

Determining the concentrations of cadmium, arsenic, copper, manganese, mercury, lead, zinc, chromium, manganese and iron requires employing various analytical methods. Techniques such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) or Atomic Absorption Spectroscopy (AAS) arc commonly used for precise quantification due to their ability to detect trace metals with high sensitivity and specificity. Rigorous quality control procedures, including the use of certified reference materials and blank samples, are essential to ensure the accuracy and reliability of the results. Analysing these metal concentrations in sediment provides valuable insights into the sources of environmental pollution, potential ecological impacts, and risks to both human health and aquatic ecosystems.

Fig 3.6: Testing for presence of heavy metals with ICP-MS

Table 3.2: Determination of physio-chemical parameters

Sl No.	Parameter	Units	Methods of test ref. to
1.	pH	No unit	IS 3025 Part 1 (1983)
2.	Sulphate	mg/l	IS 3025 Part 24 (1986)
3.	Hardness	mg/l	IS 3025 Part 21 (1983)
4.	Total dissolve solids	mg/l	IS 3025 Part 16 (2023)
5.	As	mg/l	IS 3025 Part 37 (1988)
6.	Cr	mg/l	IS 3025 Part 52 (2003)
7.	Cd	mg/l	IS 3025 Part 41 (1992)
8.	Hg	mg/l	IS 12041 (1987)
9.	Pb	mg/l	IS 12074 (1987)
10.	Zn	mg/l	IS 3025 Part 49 (1988)
11.	Mn	mg/l	IS 1473 (2004)
12.	Fe	mg/l	IS 3025 Part 53 (2003)
13.	Al	mg/l	IS 12107 Part 3 (1987)

Table 3.3: Water quality specification as per IS 10500:2012

Sl No	Parameter	Units	Acceptable limit	Permissible limit
1.	pH	No unit	6.5-8.5	No relaxation
2.	Sulphate	mg/l	200	400
3.	Hardness	mg/l	200	600
4.	Total dissolve solids	mg/l	500	2000
5.	As	mg/l	0.01	0.05
6.	Cr	mg/l	0.05	No relaxation
7.	Cd	mg/l	0.003	No relaxation
8.	Hg	mg/l	0.001	No relaxation
9.	Pb	mg/l	0.01	No relaxation
10.	Zn	mg/l	5	15
11.	Mn	mg/l	0.1	0.3
12.	Fe	mg/l	0.3	No relaxation
13.	Al	mg/l	0.03	0.2

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GENERAL

In this study, the aim is to analyse the extent and impact of contamination caused by acid mine drainage in the Margherita region. By examining water samples from various points within the affected area, we will assess the levels of acidity, metal concentrations, and overall water quality. Our analysis will provide insights into the spatial distribution of contaminants and their potential ecological and human health risks. Understanding the dynamics of AMD contamination is crucial for developing effective remediation strategies and informing policy decisions aimed at mitigating its adverse effects. Through this investigation, we hope to contribute to the broader discourse on sustainable mining practices and environmental protection.

4.2 ANALYSIS OF TEST RESULTS

Table 4.1: Test results for Surface water

Sl No	Parameter	Units	Borgolai	Tipong	Ledo
			Sample 1	Sample 2	Sample 3
1.	pH	No unit	3.75	4.61	4.52
2.	Sulphate	mg/l	1675	1455	1765
3.	Hardness	mg/l	1890	1475	2150
4.	Total dissolve solids	mg/l	3250	2750	3300
5.	As	mg/l	1.6	1.65	1.8
6.	Cr	mg/l	8.3	7.5	9.2
7.	Cd	mg/l	2.6	1.5	1.2
8.	Hg	mg/l	1.2	0.8	1.5
9.	Pb	mg/l	5.3	3.2	4.5
10.	Zn	mg/l	2.5	1.9	1.9
11.	Mn	mg/l	24	18	19
12.	Fe	mg/l	159	154	173
13.	Al	mg/l	1.9	1.8	1.95

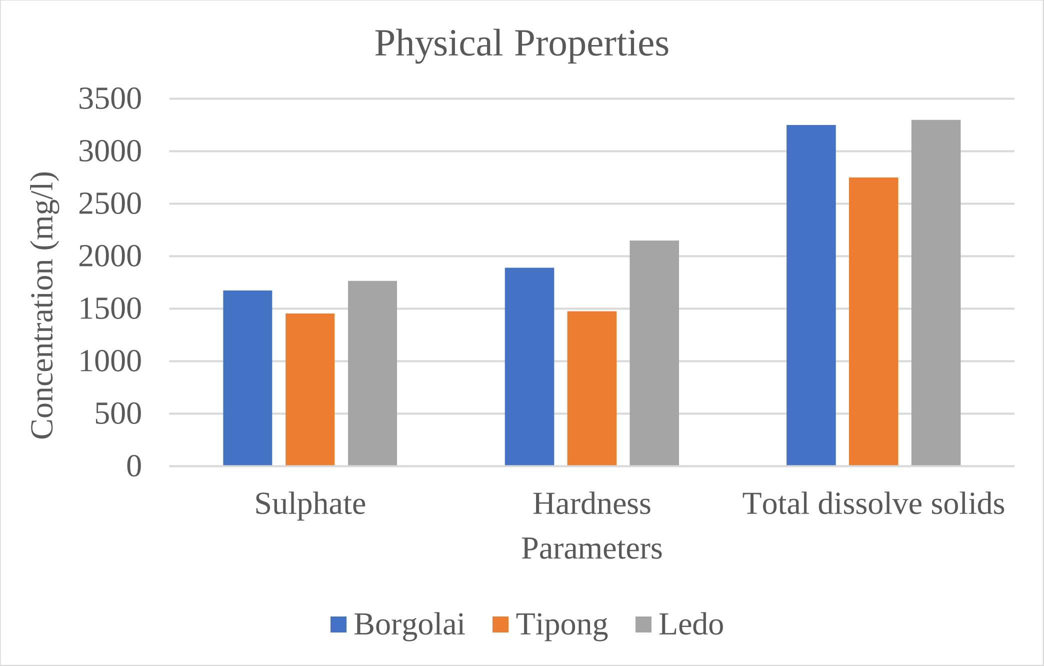

Fig 4.1: Concentration of physical properties.

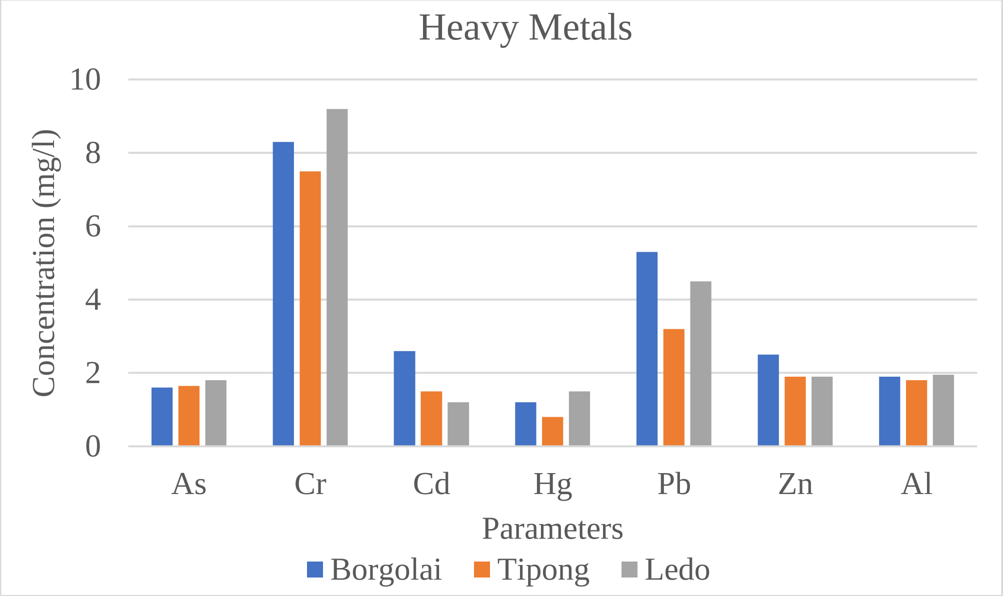

Fig 4.2: Concentration of heavy metals.

Table 4.2: Test results for Ground water

Sl No	Parameter	Units	Borgolai	Tipong	Ledo
			Sample 4	Sample 5	Sample 6
1.	pH	No unit	6.82	6.72	6.55
2.	Sulphate	mg/l	875	672	1005
3.	Hardness	mg/l	545	452	475
4.	Total dissolve solids	mg/l	1020	740	845
5.	As	mg/l	0.07	0.045	0.065
6.	Cr	mg/l	0.02	0.01	0.02
7.	Cd	mg/l	0.001	0.002	0.001
8.	Hg	mg/l	0.005	0.003	0.002
9.	Pb	mg/l	0.02	0.01	0.01
10.	Zn	mg/l	0.07	0.02	0.05
11.	Mn	mg/l	0.3	0.1	0.5
12.	Fe	mg/l	5.5	7.8	4.5
13.	Al	mg/l	0.09	0.07	0.15

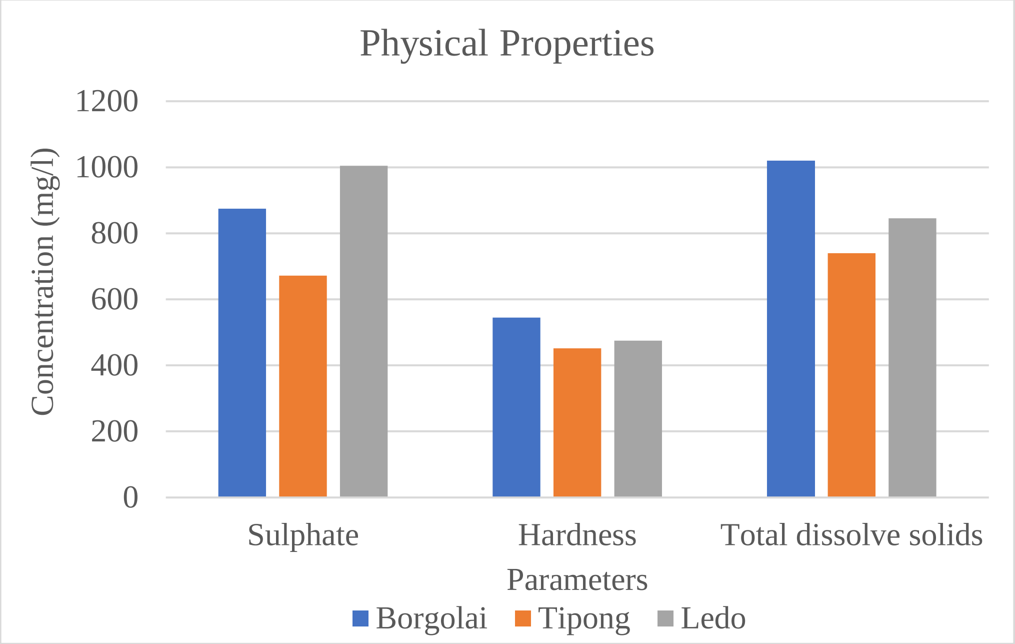

Fig 4.3: Concentration of physical properties.

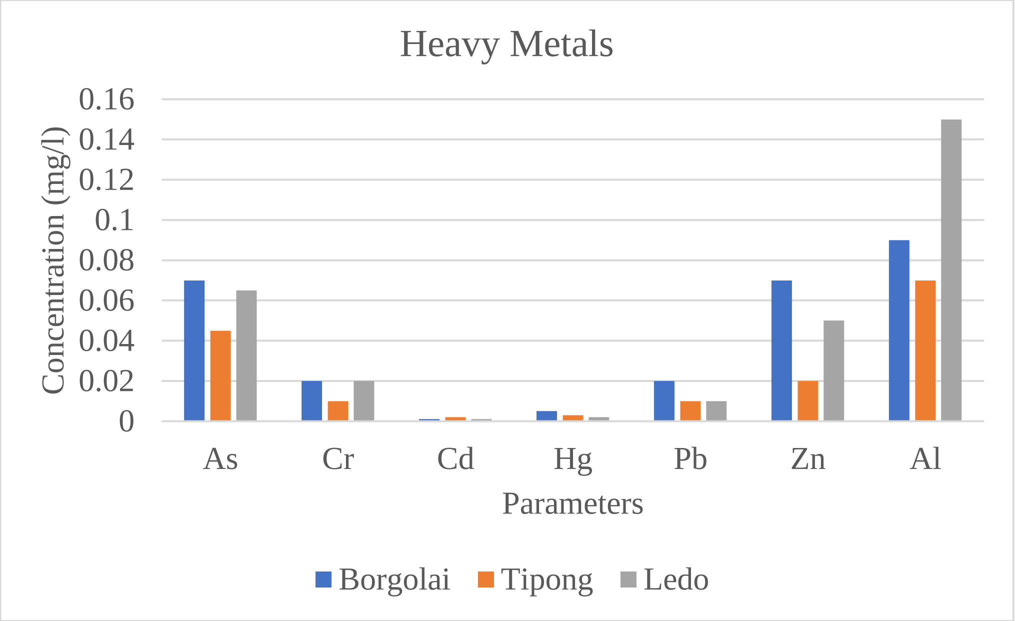

Fig 4.4: Concentration of heavy metals.

Table 4.3: pH of samples with respect to different proportion of lime.

Sl No	Lime (g)	pH					
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
1.	0.1	3.15	4.21	4.12	6.45	6.22	5.95
2.	0.2	3.92	4.51	4.32	7.12	6.92	6.93
3.	0.3	4.24	5.82	5.62	7.44	7.24	7.24
4.	0.4	5.54	6.52	6.47	7.96	7.82	8.14
5.	0.5	8.25	8.43	7.53	8.25	8.21	8.75
6.	0.6	9	9.15	8.32	8.95	9.55	9.54
7.	0.7	10.11	9.31	9.52	10.11	10.65	10.22
8.	0.8	10.05	9.35	9.91	11.04	10.95	10.97
9.	0.9	10.03	9.2	10.08	11.23	10.55	11.52
10.	1	9.03	9.15	10.25	11.93	10.06	11.75
11.	1.1	-	-	10.32	11.55	-	11.72
12.	1.2	-	-	9.82	-	-	11.64

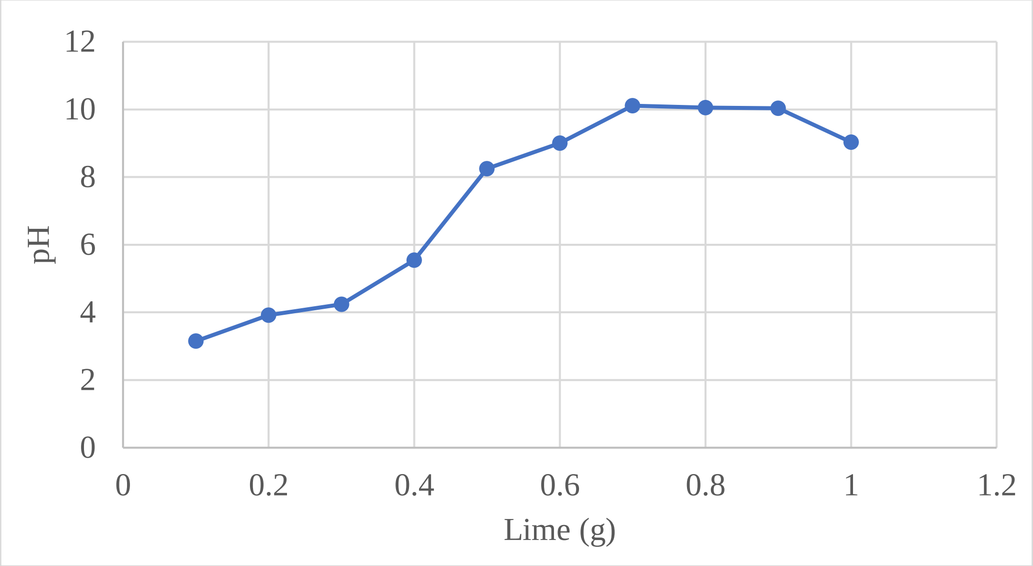

Fig 4.5: pH vs Lime for Sample 1

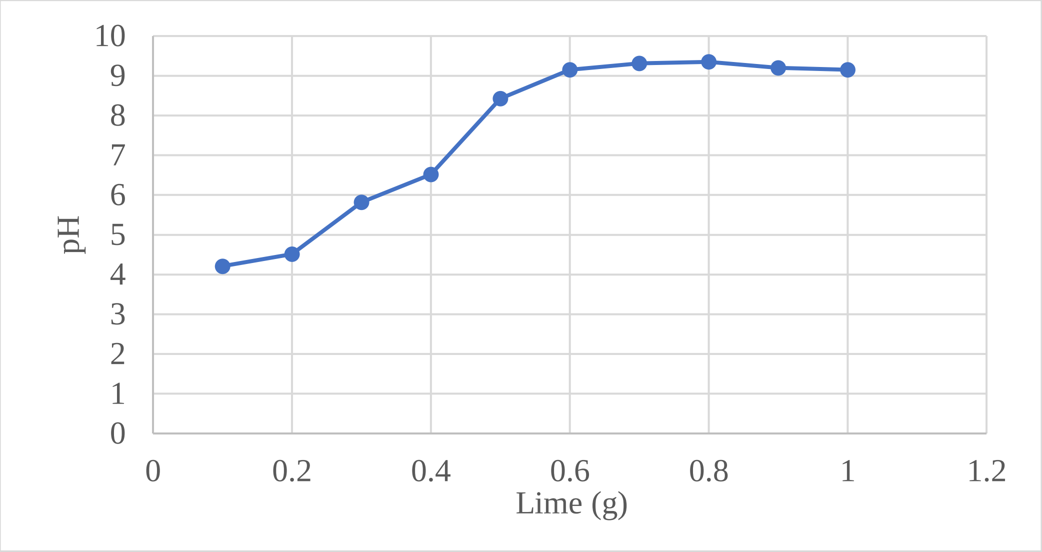

Fig 4.6: pH vs Lime for Sample 2

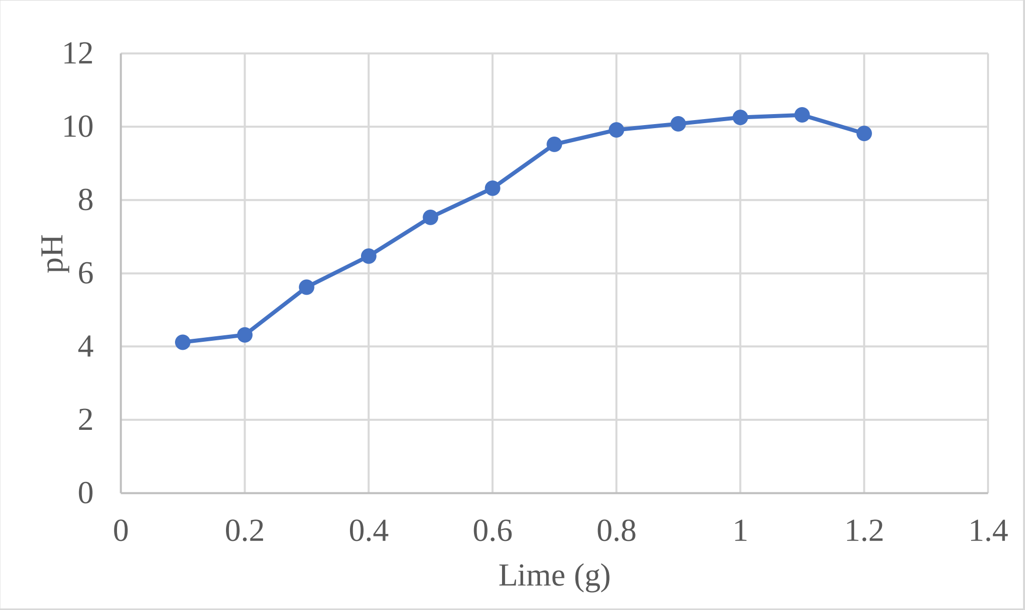

Fig 4.7: pH vs Lime for Sample 3

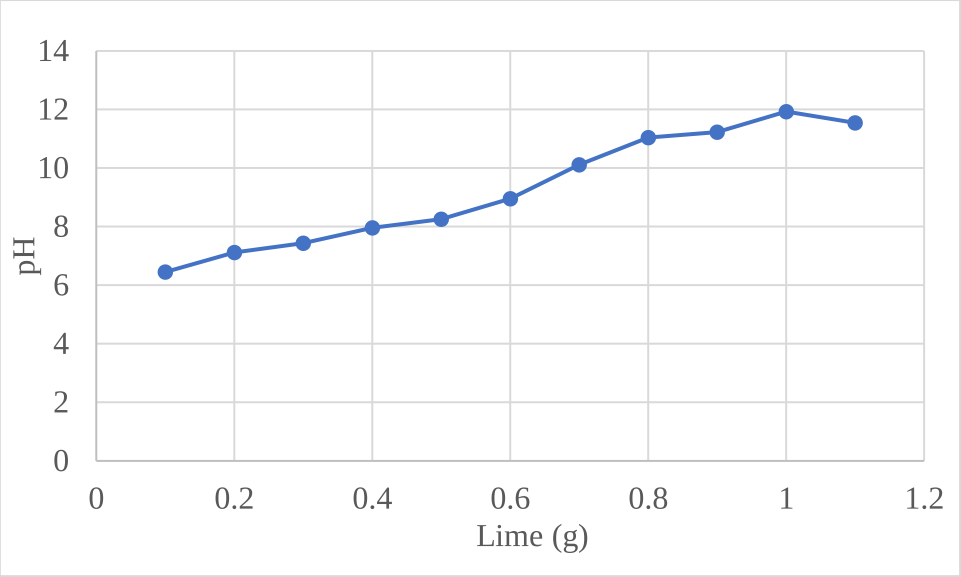

Fig 4.8: pH vs Lime for Sample 4

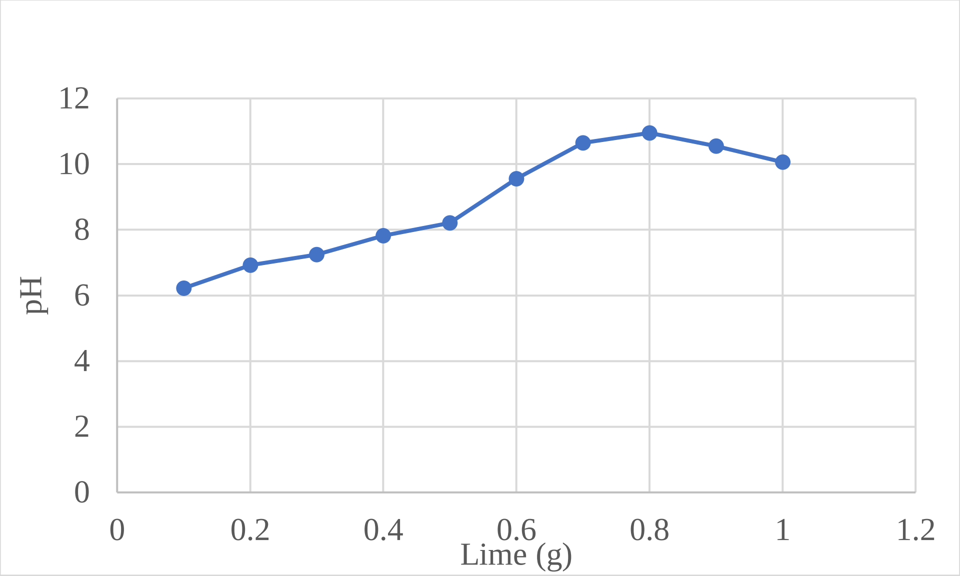

Fig 4.9: pH vs Lime for Sample 5

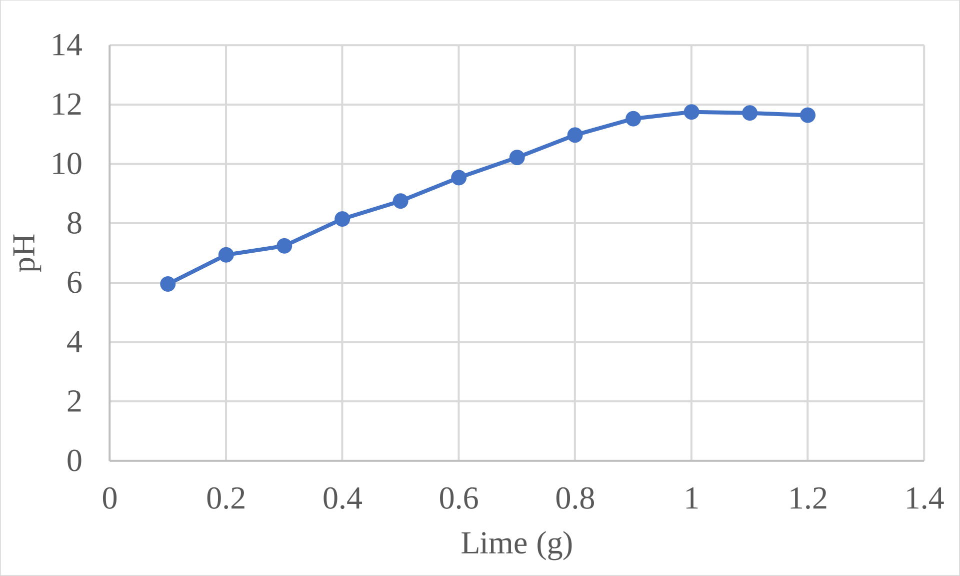

Fig 4.10: pH vs Lime for Sample 6

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE STUDY

5.1: INTRODUCTION

The analysis of the test highlights the significant role of coal particularly in India, while also addressing the severe environmental challenges posed by acid mine drainage resulting from coal mining activities. This chapter includes several remedies for post-mining areas and also gives a scope of future research in this field.

5.2: CONCLUSIONS

Following conclusions can be made based on the analysis and interpretation of the results:-

1. The urgent need for effective treatment methods such as neutralization, is emphasized to mitigate the detrimental impacts of acid mine drainage on water quality and public health.
2. The release of heavy metal can be controlled by pre-mine planning and implementing mining and reclamation techniques to control, minimize or eliminate the problems.
3. The results show that high level of sulphate, hardness and total dissolve solids in the extinct mines than the existing mines. Specially, the concentration of these were found more in the extinct coal mines i.e. Borgolai and Ledo.
4. The results of the tests for surface water show that the concentration of chromium, lead, manganese, iron and aluminium in the extinct coal mines are more than in the existing coal mine (Tipong).
5. The results of the tests for ground water also show that the concentration of arsenic, chromium, zinc, manganese and aluminium in the extinct coal mines are more than in the existing coal mine.
6. In all the samples the concentration of iron was found to be the highest.

5.3: SCOPE FOR FUTURE STUDY

The future scope of investigation on acid mine drainage and its remedies involves interdisciplinary approaches, integrating advanced technologies and sustainable practices. This study can be continued by considering the following key areas:

1. Application of advanced characterization and monitoring technologies to determine the spread of AMD, and its chemical composition.
2. Using novel remediation techniques to treat the AMD waste generation by application of nanotechnologies, bioremediation advances, etc.
3. Incorporating predictive tools and including covering tailings to minimize exposure can help mitigate AMD risks.
4. Making of adaptive management strategies to prevent climate change impacts that might influence AMD formation and spread.
5. Collaborative research between Engineers, Geochemists and Economists might help minimize environmental damage and transform AMD from a liability into a resource opportunity.

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