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Influence of Aggressivity of Water on the Long Term Sustainability of Hydro Power Structures – A Review

By Beena Anand

Abstract- To fulfil country's irrigation and power requirements various large capacity dams have been constructed on major rivers in last 50 years. The long term sustainability of these structures is largely dependent on hydro-environment and the capacity of these structures to resist weathering action, chemical attack, abrasion, or any other process of deterioration. The concrete deterioration is directly influenced by various geographical, climatic and ecological conditions. The chemical reactions between cement and water enable the setting and hardening of cement, resulting in a binding medium for the aggregates and development of strength. Quality of water plays an important role in the production of concrete. There are some chemical environments under which the useful life of even the best concrete will be affected adversely. The aggressiveness of water is dependent on the pH value, the total dissolved salts, the degree of hardness, soluble chlorides, sulphates, carbonation, temperature and alkalinity etc. Understanding these conditions permit measures to be taken to prevent or reduce deterioration.

Keywords: aggressivity; durability, leaching; seepage; hydro-environment.

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INFLUENCEOFAGGRESSIVITYOFWATERONTHELONGTERMSUSTAINABILITYOFHYDROPOWERSTRUCTURESAREVIEW

Strictly as per the compliance and regulations of:

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Abstract- To fulfil country's irrigation and power requirements various large capacity dams have been constructed on major rivers in last 50 years. The long term sustainability of these structures is largely dependent on hydro-environment and the capacity of these structures to resist weathering action, chemical attack, abrasion, or any other process of deterioration. The concrete deterioration is directly influenced by various geographical, climatic and ecological conditions. The chemical reactions between cement and water enable the setting and hardening of cement, resulting in a binding medium for the aggregates and development of strength. Quality of water plays an important role in the production of concrete. There are some chemical environments under which the useful life of even the best concrete will be affected adversely. The aggressiveness of water is dependent on the pH value, the total dissolved salts, the degree of hardness, soluble chlorides, sulphates, carbonation, temperature and alkalinity etc. Understanding these conditions permit measures to be taken to prevent or reduce deterioration.

Some case studies related to some peculiar problems encountered during the pre and post construction investigations with special reference to deterioration of concrete due to highly acidic water quality faced at Kopili H.E. Project, Lower Kopili HE Project and Myntdu HE project, all the projects located in North Eastern part of India are presented in this review. A brief discussion on the findings of filed observations made in recent past by the CSMRS over the environmental aspects of water quality and its detrimental effects already caused on structures has also been done. Few remedial measures for the upgradation of catchment area to control the acidification of rivers are also discussed here.

Keywords: *aggressivity; durability, leaching; seepage; hydro-environment.*

I. Introduction

These are the three projects facing a lot of problems due to very low acidity of river water. These are Kopili HE Project, Lower Kopili HE Project (both in Assam) and Myntdu Leska HE Project located in Meghalaya. Studies for the two projects viz Lower Kopili HE Project and Myntdu- Leska HE Project were done at the DPR stage of the projects while for Kopili HE Project the study for the damages due to acidic environment was done post commissioning of the project. All the three projects are located in the nearby area of Jaintia Hills region of Meghalaya, one of the seven north eastern states of India possesses rich deposits of coal at relatively shallow depth. Coal found in this area contains high sulphurous content. The state being a Sixth Schedule State, its autonomy gives freedom to the people to mine at their own will. Most of the mining activities are small scale units controlled by individuals who own the land. Mining operations has led to extensive environment degradation in the area. For assessing the impact of coal mines the catchment area of rivers Myntdu, Laichiki, Lamu, Makjai, Umshangphu, Khakar and Kopili which flow through the coal rich belt of the state has been surveyed. The rivers Myntdu, Laichiki, Lamu, Makjai, Umshangphu impound the reservoir of Myntdu-Leshka Hydro Electric project while rivers Khakar and Kopili impound the twin reservoirs of Kopili Hydro Electric project.

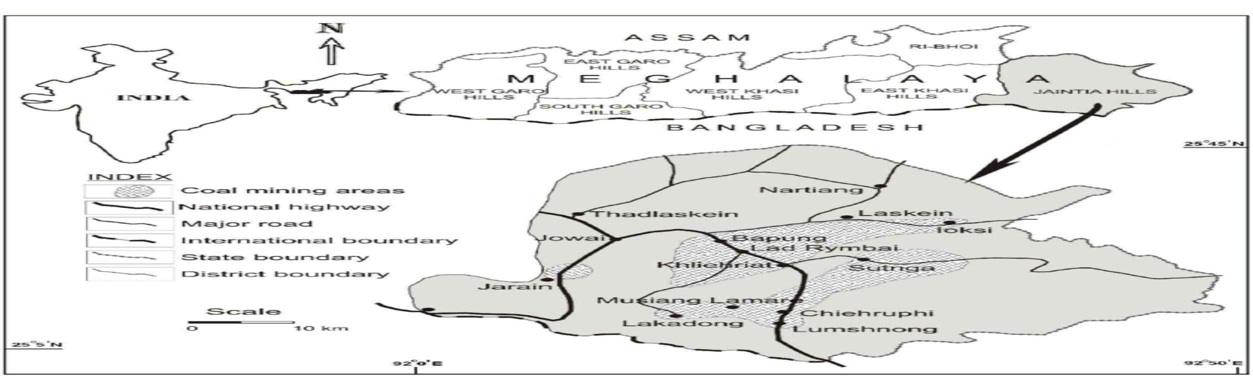

Figure 1: Outline map showing the coal mining areas in Jaintia Hills of Meghalaya in northeast India

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On the request of Project Authorities, CSMRS took the investigation work. The thrust area of in situ & laboratory water quality studies of river Kopili & its tributaries was:

- To assess the water quality to ascertain its long term effect on durability of dam concrete structures.
- To investigate acidity problem of river Kopili at Dam axis, powerhouse site and adjoining Nallahs & possible remedial measures thereof.

Acid attack deteriorates concrete and steel components of project, and plays a major role towards the high cost of it in a number of ways. Some of the photographs below in *Figure 2* show the small scale rat-hole mining abandoned mines filled with rain water causing the acidification of river water.

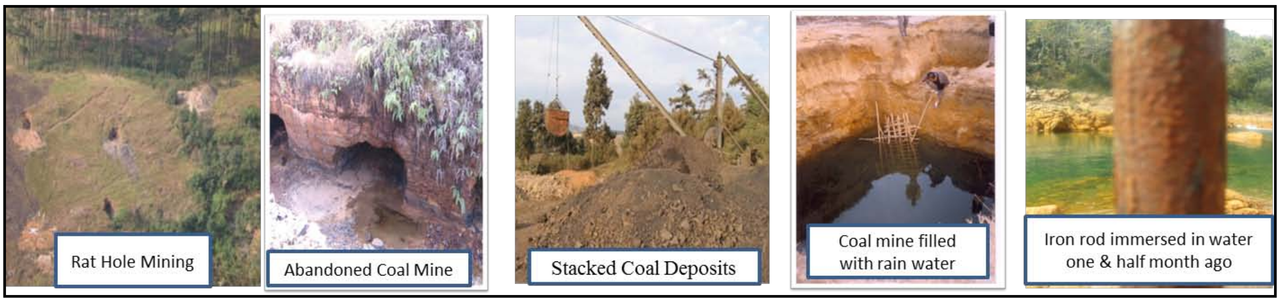

Figure 2: Rat-hole mining, abandoned mines filled with rain water causing the acidification of river water

During the field visit (s), the in-situ parameters like pH, conductivity and temperature of water samples were recorded along with the visual impact of aggressive water on the river water, boulders etc. At some stretches, pH of river water was recorded as low as 3.65. Photographs below in *Figure 3* showing the impact of aggressive water on the river water, boulders etc.

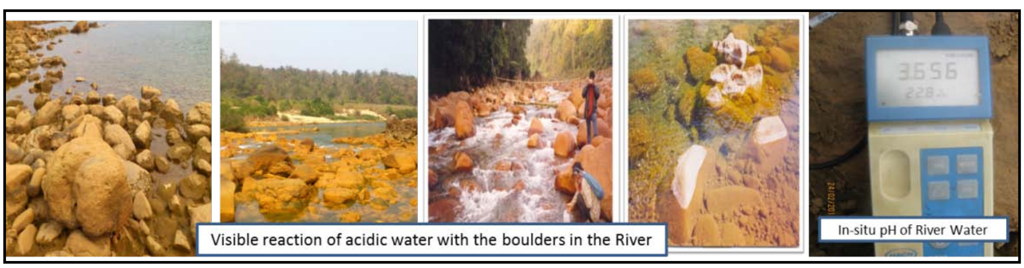

Figure 3: Impact of aggressive water on the river water, boulders

Figure 4 shows the signs of distress observed in the concrete structure and various other components of Kopili HE project due to acidic water impounded in reservoir and used for power generation.

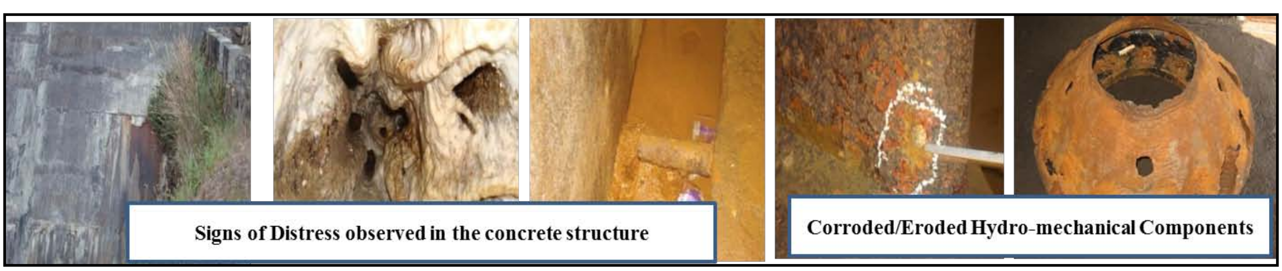

Figure 4: Signs of distress observed in the concrete structure and various other components

II. Problem Encountered

The richness of Jaintia Hills region in minerals is posing the most serious problem as the rivers flowing through the area have turned acidic with very low pH, making them "unfit" for human consumption, hence the population is reeling under thirst around the region of plenty of water. Also the vegetation, flora and fauna, particularly the aquatic life, has also been suffering because of low pH of rivers of the area [1]. Mining is done by private people at their wish and the state government has no control over the rich coal lobby [2]. Most of the time coal mines in Jaintia Hills are abandoned after extracting the mineral. Heavy metals are left exposed which subsequently react with water/oxygen to form different chemicals. Due to heavy rains in the area, these harmful chemicals make their way to fresh water bodies causing a number of problems due to acidification and pollution of rivers and streams. Though scientists and environmentalists all along have been raising fingers at the unscientific coal mining practiced in Jaintia Hills, yet success of seems be far away.

Up to year 2006 after commissioning of its first stage in 1984 of Kopili HE Project, the project has been continuously serving the region smoothly by providing electric energy. Frequency of outages was rare till year 2006 which suddenly increased abruptly. Further investigations revealed that water in the reservoir has turned acidic. During post outage maintenance it was detected that the reason of outages was corrosion/erosion of hydro-equipment. The risk of exposing hydraulic structures and equipment to unforeseen aggressive environment which is pushing the plant to a perilous situation necessitated detailed investigation of the problem.

a) Acidification of water due to mining activities: Acid Mine Drainage (AMD)

Basically two processes namely Acid Mine Drainage (AMD) and Acid Rock drainage (ARD) are responsible for the acidification of River/stream/Oceanic water [3]. Acid mine drainage (AMD) refers to the outflow of acidic water from a mining site. In most cases, this acid comes primarily from oxidation of iron sulfide (FeS_2, also known as pyrite or "fool's gold"), which is often found in conjunction with valuable metals Acid mine drainage is a major problem with many hard rock mines, including almost all mines where the metal ore is bound up with sulfur (metal sulfide mines). A significant number of coal mines also suffer from acid mine drainage. Acid mine drainage is a worldwide problem, leading to ecological destruction in watersheds and the contamination of human water sources by sulfuric acid and heavy metals, including arsenic, copper, and lead. Once acid-generating rock is crushed and exposed to oxygen and the surface environment, acid generation is very difficult to contain or stop, and can continue for tens or thousands of years until the available sulfide minerals are exhausted. Presence of certain bacteria e.g. Thiobacillus ferrooxidans and Thiobacillus thioxidans promote sulphur and/or iron oxidation (Corrans et al., 1972).

b) Biological Factors for the acidification of Water Bodies

In situations where bacterial acceleration of sulphide oxidation is significant (principally at low pH), the bacterial population density and rate of population growth determine the bacterial activity and the rate of acid generation. Population density and growth of bacteria are a function of a number of factors such as carbon availability (in the form of carbon dioxide), presence of electron donor (ferrous iron or sulphur), nutrient availability (i.e., nitrogen, phosphorus for production of biomass), oxygen (promotes growth of aerobic bacteria and is an electron acceptor; kills strictly anaerobic bacteria) and temperature (most bacteria demonstrate optimal growth below approximately 70°C).

Virtually sulphur and iron are omnipresent at mining sites. Microorganisms are highly efficient in manipulating their immediate environment, either at their own or in a symbiotic relationship with other microorganisms. Hence, the actual reaction site environmental conditions is more conducive to elevated oxidation rates than it is predicted by measurements in the bulk liquid phase. [4].

Certain bacteria accelerate the rate of reactions of sulphide oxidation. Bacteria of the *Acidithiobacillus* species are of particular importance with regard to sulphide oxidation. *A. ferroxidane* is capable of catalyzing both the oxidation of sulphur and ferrous iron while *A. thiooxidanes can* oxidize sulphur only. Other members of the *Acidithiobacillus* species are also capable of catalyzing pyrite oxidation like certain members of the genera *Sulfolobus* and *Lepto-spirillium.* [5].

c) Water Quality Investigation

Initially the investigation work of Myntdu-Leska HE, Meghalaya project was done for its DPR. The high acidic nature of Myntdu River was established by conducting detailed field and laboratory analysis of water samples. In the meanwhile already constructed and operational Kopili HE Project, Assam started facing troubles in operation and frequent outrages were reported after 2006. Investigation revealed the similar high acidic nature of Kopili River as that of Myntdu River. Thn came the Lower Kopili HE Project on the Kopili River for its DPR studies.

Water quality investigation was carried out for three different seasons viz pre-monsoon, post monsoon and lean season to access the water quality and its impact on the long term durability of concrete and other equipment. Water samples were subjected to both in-situ and detailed laboratory analysis. The in situ and laboratory parameters were determined as per standard analytical procedures laid down in Indian Standard: 3025–1986 "Methods of Sampling and Test (Physical and Chemical) for Water used in the Industry". Wherever necessary, reference was also made to the procedure laid down in Standard Methods for the Examination of Water and Waste Water" published by American Public Health Association and Water Pollution Control Federation, USA, 1985. Water samples collected by CSMRS from the various locations of the catchments show the pH value ranging between 2.76 to 5.98. Coal mining in the catchment area is the main cause of acidity of reservoir water. *Figure 5* below shows very low pH of River water at various stretches of Kopili River.

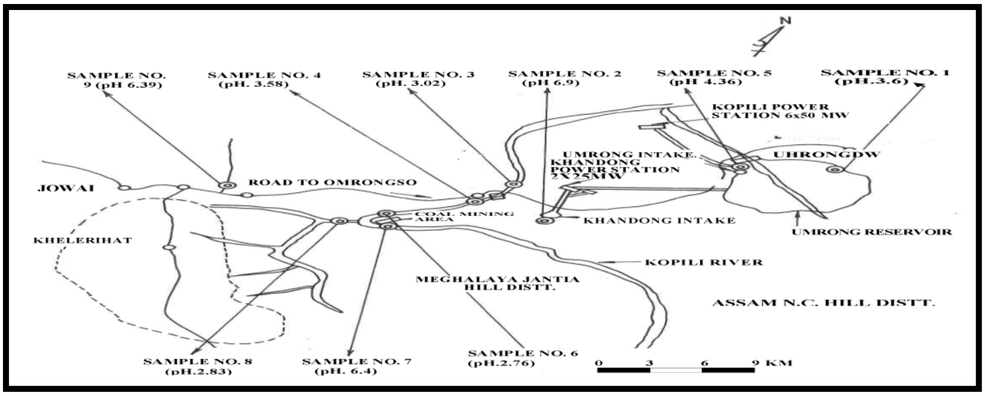

Figure 5: pH at various sampling locations in the catchment area of KHEP

Due to highly acidic nature of water, the deleterious effect on concrete and other hydro-components of structures are possible in the form of:

- Leaching of lime from concrete
- Loss of concrete strength over a period of time
- Possibility of attack on metallic portion e.g. Turbine blades, reinforcement etc.
- As per the BIS code IS: 456 – 2000, environmental conditions are "Extreme" and the requirement of concrete should be as per the codal provisions.

d) Field and Laboratory Analysis

In-situ parameters like pH, $CaCO_3$ saturated pH, conductivity, temperature, salinity, sulfide and ammonium concentration were recorded.

Parameters like cations (calcium, Magnesium, Sodium, Potassium); Anions (Carbonate, Bicarbonate, Chloride & Sulphate) were determined in the laboratory.

e) Degree of Aggressivity of Water

Degree of aggressivity of water is established under the guidelines laid down in following relevant national and international codes and practices:

- United States Bureau of Reclamation Sstandard (USBR) for sulphate aggressivity.
- French National Standard, p18-011, May 1985 for assessing aggressivity due to pH, Ammonium, Magnesium and Sulphate ions.
- International Commission on Large Dams, ICOLD Bulletin No. 71 "Exposure of Dam Concrete to Special Aggressive Waters – Guidelines and Recommendations, 1989" for assessing aggressivity of soft water.
- Indian Standard 456-2000 "Plain and reinforced concrete – Code of practice" (fourth revision).
- Extracts from ACI 515-1R5, Para 2.5, 1991, "Susceptibility of concrete to attack by chemicals" and book titled "Concrete Corrosion, Concrete Protection" Imre Biczok, 1991.

III. Observations & Recommendations

Out of three season's pH observations, the pH values of river locations are noticed in highly acidic range in pre-monsoon (February 2015) water quality observation. In monsoon (June 2016) season, the pH values marginally increases in the range of 6.68 to 7.85. While in post monsoon season (October 2016), pH values become again slightly acidic in the range of 5.49 to 6.15. [Figure 6].

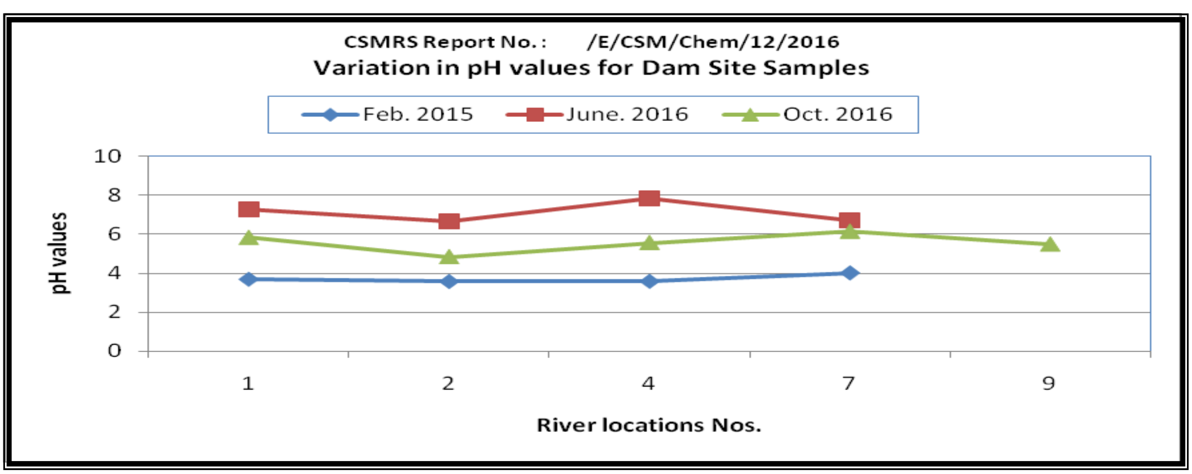

Figure 6: Variation of pH values in different seasons for river water locations

Out of three season's conductivity values, the conductivity values of post monsoon season are noticed in the range 93.7 to 151.2 micromhos/cm. However, the conductivity values remain lower in all seasons in the range of 76.7 to 151.2 micromhos/cm. [Figure 7]

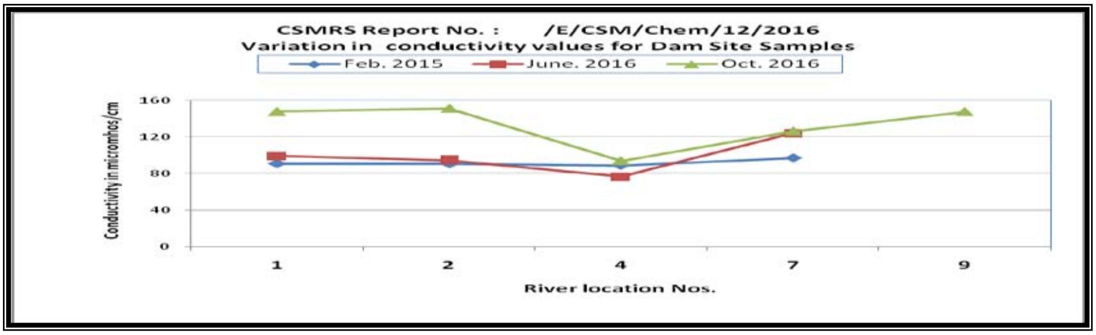

Figure 7: Variation in conductivity values in different seasons for river water locations

The water quality evaluated during pre-monsoon, monsoon and post monsoon seasons for river and Nallah sites. Seasonal variation in pH is appreciable and remains in acidic range for most of river and Nallah locations during pre-monsoon and post monsoon seasons. Further, the type of the water under reference is "soft" (in accordance to calculated Langelier Index Values of water samples) in nature as the conductivity and anions and cations concentrations recorded lower side throughout the period of observations. However, due to discharge conditions, the pH values improve in river and Nallah locations in monsoon season. After the study of the analytical data of the water samples, the observations along with remedial measures suggested are discussed here.

a) Environmental Exposure Conditions

After the evaluation of water quality data for three seasons, the overall water quality of the various sites of the project may be classified as "severe" category as far as its attack on concrete is concerned. The details of various environments are given in Table 3 under clauses 8.2.2.1 and 35.3.2 of Indian Standard: 456 – 2000.

Clauses 8.2.2.1 and 35.3.2 of IS: 456 – 2000

Sl. No.	Environment	Exposure Conditions
i	Mild	Concrete surfaces protected against weather or aggressive conditions, except those situated in coastal area.
ii	Moderate	Concrete surfaces sheltered from severe rain or freezing whilst wet Concrete exposed to condensation and rain ; Concrete continuously under water; Concrete in contact or buried under non aggressive soil/ground water Concrete surfaces sheltered from saturated salt air in coastal area.
iii	Severe	Concrete surfaces exposed to severe rain, alternate wetting and drying or occasional freezing whilst wet or severe condensation. Concrete completely immersed in sea water Concrete exposed to coastal environment
iv	Very severe	Concrete surfaces exposed to sea water spray, corrosive fumes or severe freezing conditions whiles wet Concrete in contact with or buried under aggressive sub-soil/ground water
v	Extreme	Surface of members in tidal zone Members in direct contact with liquid/solid aggressive chemicals

b) Study of Nature of Coal Samples

During the field survey, it was observed that unscientific way coal mining activity might be undertaking in the catchment area probably using Rat Hole Technology. In this method, after excavation of coal, the holes and pits are generally left open and unattended. As the region receives heavy rains during most of the time of the year, these ditches get filled with rain water. Under the feasible/favourable conditions, left over coal reacts with water and in turn as a result sulphuric acid is produced and the acidic water finds its way into the river. The interaction of water with coal mine lowers the pH of the water, when the river water becomes stagnant.

To ascertain the effect of interaction between coal and water with respect to change in pH, conductivity and sulphate concentration, a study was carried out. Coal samples were collected from the coal mines located in the catchment area of Myntdu River (Sample 1) and Kharkor River (Sample 2). These

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samples were kept in distilled water. The pH, conductivity and sulphate concentration values of the supernatant liquid were recorded till 180 days. The results of these observations are depicted in the Figures 8, 9 and 10 below:

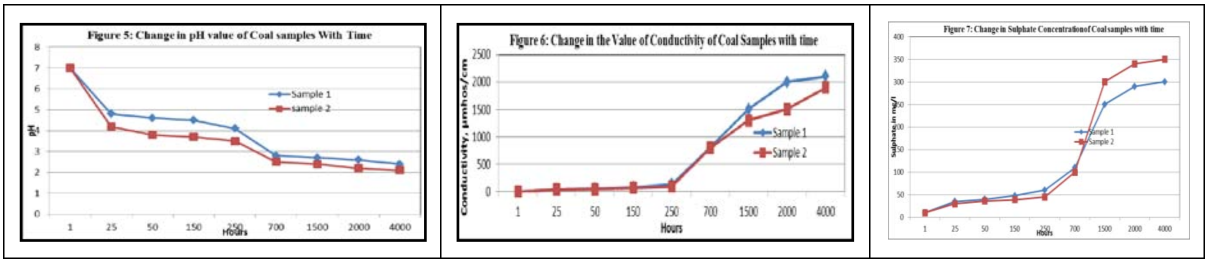

Figure 8-10: Variation in the values of pH, conductivity and sulphate concentration of the two coal samples in distilled water with time

c) *Minerology of Coal*

Coal sample was subjected to the X-ray diffraction for its mineralogical identification. X-ray diffraction study was done with Match software using ICDD database. The coal sample predominantly showed presence of minerals Pyrite, Nacrite, Muscovite and Kaolinite.

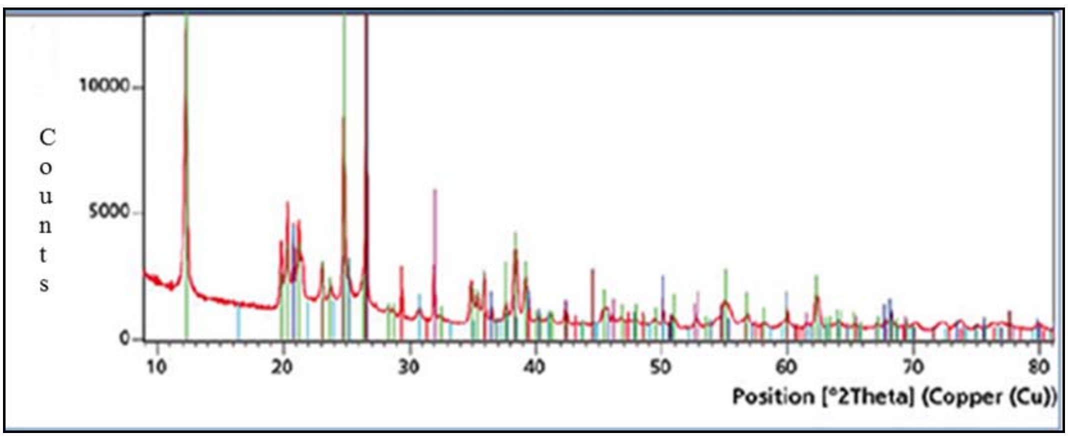

Fig 11: X-Ray Diffractogram of Coal Sample

d) *Chemistry of Acid Mine Drainage*

Generally the rivers/streams existing in the close proximity to the coal mines/ coal dumping sites in the catchment area are observed having low pH with slightly elevated levels of dissolved metals. The formation of AMD is primarily a function of the geology and hydrology of the area along with the mining technology employed. The amount of iron sulphide in an ore deposit or mine waste plays a crucial role in determining the characteristics of the mine drainage. During the formation of ore deposits, sulphide minerals are formed in the absence of oxygen under reducing conditions. When exposed to atmospheric oxygen or oxygenated waters generating from mining, mineral processing, excavation, or other earthmoving processes, sulphide minerals become unstable and get oxidized.

When pyrite of coal comes in contact with water, a series of complex geo-chemical and microbial reactions occur resulting in the oxidation of pyrite into oxides of iron and sulphuric acid. Formation of sulphuric acid lowers the pH of water. Due to low pH, mobility of metal ions increases and the concentration of dissolved metal ion in water increases which stays dissolved in solution till the pH rises to a level where precipitation of metal occurs. Pyrite weathering and the overall reaction may be summarised as follows:

$$2\,FeS_2 + 7\,O_2 + 2\,H_2O \rightarrow 2\,FeSO_4 + 2\,H_2SO_4$$

$$4\,FeSO_4 + O_2 + 2\,H_2SO_4 \rightarrow 2\,Fe_2\,(SO_4)_3 + 2\,H_2O$$

$$7\,Fe_2\,(SO_4)_3 + FeS_2 + 8\,H_2O \rightarrow 15\,FeSO_4 + 8\,H_2SO_4$$

Once the mining activity is over, these holes and pits are left unattended. During monsoon season these get filled with water. This acid joins the reservoir through various tributaries flowing through this region turning the river water acidic and unfit for consumption.

e) *Detrimental Effects of Acidity*

Low pH of water is a major cause of deleterious effects on concrete and various hydro mechanical components of the project. It may cause:

- Leaching of lime may occur from concrete
- Loss of concrete strength over a period of time
- Frequent outages in power generation due to corrosion and erosion of hydro mechanical components.

Kopili HE project in particular is suffering due to frequent outrages in power generation due corrosion and erosion of hydro mechanical components. A huge amount of economy and man power is being involved in the process of repair/rehabilitation of all the equipment after every 6-8 months.

f) Steps taken by Authorities

Even after a lot of hue and cry by scientists/engineer/NGOs, media [9, 10] and a ban imposed by the National Green Tribunal (NGT) on unscientific rat-hole mining of coal in Meghalaya, the State Government did not took the matter as seriously as it should be. The performance audit report on the operations of Meghalaya's mining department by the Comptroller and Auditor General of India (CAG) observed: "*There was serious air, water and environmental pollution caused* by *illegal, unregulated and indiscriminate mining being carried on in various parts of the state of Meghalaya*". The report rapped the state government for not taking effective steps to control acid mine drainage as suggested by the pollution control boards. The state pollution control board began investigation in 2011 into the sudden death of fishes in Lukha River in Jaintia Hills district and reported the matter for information and necessary action in 2012. According to CAG the acidic water caused severe corrosion in the machinery of two of NEEPCO projects in 2006-07 causing frequent power outages due to the failure of cooler tubes and cooling water pipes in the power station [11]. In the year 2008-09 major Central agencies and authorities like the Central Water Commission, Central Electricity Authority and Central Soil and Material Research Station Station, after thorough investigation confirmed that acidic water had badly affected the Kopili HE Plant. Of late the Meghalaya government has assured a separate fund for reclaiming all the degraded lands due to coal mining to make them fit for vegetation and farming activities.

Also study has been performed using Cladophora algal which is found in abundance at site, to observe its effect on the improvement of pH of water [12-18]. Though the results seemed very promising, however, algae based methods of abating AMD are not the ultimate solution to the problem and there is room for more studies.

g) Other Environmental Effects due to high acidic nature of River Water

The increased acidity caused by acid mine drainage has a range of negative effects depending on the severity of the pH change. Many river systems and former mine sites are totally inhospitable to aquatic life, with the exception of "extremophile" bacteria. Additionally, heightened acidity reduces the ability of streams to buffer against further chemical changes. In addition to the direct negative effects of increased acidity and the increased release of toxic metals, an additional problem can also be created when the acid reacts with the rock that neutralizes it. As the water becomes less acidic, metals and other solids come out of solution. One of these precipitates, known as "yellow boy," can smother life on the streambed. These streams turn a distinctive orange/red color, as their beds are coated by a solid veneer of chemical precipitate resembling brightly colored chocolate "hard sauce" or paint. (As can be seen in Figure 2 above). High acidity causes ecological harm to downstream areas which adversely affects the economy of the region too. Treatment of acid mine drainage has in many cases proved economically impossible as money can only pay for the material loss but can never repay the health problems associated with acid waters and heavy metal toxicity, loss of biological services from exterminated water organisms, and the loss of recreational and subsistence fishing and hunting opportunities.

IV. Prevention and Mitigation

There are three basic ways to limit acid mine drainage; prevent sulfuric acid from forming, neutralize the acid after it forms, or collect runoff/seepage to contain the acid.

1. To stop the formation of sulfuric acid, the waste rock and tailings from a mine must be prevented from coming in contact with oxygen. Oxygen can come from either the flowing water or air.
2. Strategies for keeping tailings separate from oxygen include submerging the tailings under still water, sealing them behind a synthetic barrier, or burying them underground.
3. Large mines typically isolate acid-generating rock underwater to reduce the rate at which oxygen interacts with the material.

The water flowing out from waste ponds needs to be treated to neutralize acidity before it is released into the environment. Often, however, acid prevention strategies fail. Isolating very large quantities of acid-generating waste and rock is difficult, either above or below ground and in many cases is effectively impossible. Once acid has been generated and toxic metals dissolved into it, the treatment of water is very expensive.

Algae strains such as Spirulina sp., Chlorella, Scenedesmus, Cladophora, Oscillatoria, Anabaena, Phaeodactylum tricornutum have showed the capacity to remove a considerable volume of heavy metals from AMD. They act as "hyper-accumulators" and "hyper-adsorbents" with a high selectivity for different elements. In addition, they generate high alkalinity which is essential for precipitation of heavy metals during treatment. [19]

Lime neutralisation remains by far the most widely applied method. This is largely due to the high efficiency in removing dissolved metals through neutralisation, combined with the fact that lime costs are low in comparison to alternatives. Lime treatment essentially consists in bringing the pH of the AMD to a point where the metals of concern are insoluble. These metals therefore precipitate to form minuscule particles, but the abundance of iron and sulfate in AMD usually renders it ineffective by forming iron hydroxide and gypsum precipitate coating on the surface of lime. At the same time TDS of water may also go up and create another set of problems for different uses of water.

V. Conclusion

The myopic vision of human has converted the treasure into curse. The rat-burrowing type of mining in very-very unscientific manner is causing the acidification of rivers and streams in the state of Meghalaya. The acidic discharge not only affecting the environment adversely but also severely eroding/corroding the installed hydro-mechanical equipment which leads to frequent outages and increased financial burden as these parts need to be repaired or replace. Though remedial reassures suggested for durable concrete may help the projects to some extent, yet the larger question is the improvement of catchment area and the quality of river water to save the dying rivers. Situation is very-very grim there and even after so tough directions and decisions taken by National Green Tribunal, no concrete result is observed at site yet as the observations made during the recent visit to the project site show that the water is highly acidic with pH as low as 3.65 at some stretches.

In order to resolve the issue of safe drinking water, environment, flora and fauna along with aquatic life, durability of major projects and above all the life of river itself, there is an urgent need for augmenting/ upgrading the catchment area of kopili River. The major step that can be beneficial in the line will be the regulation of mining activities. Due to the complexity of the issues associated with individual project and site, there is no single strategy like "one-size-fits-all", hence according to the need of each site, multifold measures including tackling the menace of AMD and eco-friendly, low cost treatment of catchment area and surface runoffs should be taken of as an immediate measure to find a sustainable solution to the issues. The ecosystem approach should be adopted to manage the environment and its natural re-sources so that economic, social and environmental benefits for a healthier and more resilient nation may be delivered.

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