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TECHNICAL COMMUNICATION

Neutralization of Acid Mine Drainage Contaminated Water and Ecorestoration of Stream in a Coal Mining Area of East Jaintia Hills, Meghalaya

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Abstract
The unscientific mining of coal without environmental safeguards in Jaintia Hills, Meghalaya has adversely affected the water resources of the area, leading to streams with a pH of 3–5. The acidic stream water is not suitable for human use and lacks aquatic life. The prevailing situation demanded immediate neutralization and eco-restoration. Considering the need, the water of Moolawar stream in Mukhaialong village, East Jaintia Hills District, Meghalaya, India was neutralized by constructing an open limestone channel (OLC) using locally available limestone. The OLC raised the pH of the stream water from 4.31 to 6.57. The near-neutral pH has promoted the reappearance of many aquatic flora and fauna, including two species of fishes and some insects. The OLC was found to be cost effective and technically feasible in this rural area and thus prompted the construction of more such projects for improvement of water quality and ecorestoration of degraded streams. Details of the study and associated improvements in water quality and aquatic ecology are reported.

Keywords Rat-hole coal mining · Open limestone channel · Water pollution · Moolawar stream · Mukhaialong village

Introduction

Coal mining can have severe environmental effects if mining is conducted without appropriate environmental safeguards (Akcil and Koldas 2006; Bian et al. 2010; Mishra and Das 2017). Eocene age coal is found in Meghalaya in all three hill regions, namely Khasi, Jaintia, and Garo Hills. The Jaintia Hills is a major coal producing area, with an estimated coal reserve of about 40 million metric tons (t). The sub-bituminous tertiary coal found in Meghalaya is characterised by high sulphur (2–8%), a high content of volatile matter and vitrinite, a low ash content, and a high calorific value. Extraction of coal in Meghalaya has been done by the primitive mining method commonly known as 'rat-hole' mining (Swer and Singh 2003).

Decades of such mining has caused: large scale land cover/land use change and denudation of forest cover (Somendro and Singh 2015), pollution of air, water and soil, degradation of agricultural fields; and scarcity of clean potable water and other natural resources (Chabukdhara and Singh 2016; Swer and Singh 2004). Acid mine drainage (AMD) generated from active and abandoned mines, coal storage sites, and overburden is currently the main surface water pollutant. The colour of the surface water varies from brownish to reddish-orange in most of the rivers and streams of the mining areas. Low pH (between 3 and 5), high electrical conductivity (EC), and elevated concentrations of sulphate and some metals (Swer and Singh 2003; Sahoo et al. 2012; Blahwar et al. 2012; Chabukdhara and Singh 2016), along with, silting by coal and sand particles are some indicators of degradation of water bodies. The mining is also responsible for degradation of aquatic habitats and loss of aquatic life (Swer and Singh 2005; Chabukdhara and Singh 2016). The contaminated surface water has degraded the agricultural fields by making the soil acidic, which has forced farmers to abandon agricultural activity. In some areas of Jaintia Hills, people do not have access to clean

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water and hence are forced to depend on the acidic water in the polluted streams. Lack of any post-mining treatment and environmental safeguards make the fragile ecosystems more vulnerable to environmental degradation.

Despite the serious environmental, health and socio-economic implications of the contaminated surface water, very little has been done to tackle these problems in Meghalaya. So, a field experiment was undertaken to improve the water quality of one of the streams by constructing an open limestone channel (OLC) using locally available limestone.

Materials and Methods

Study Site

The field experiment was conducted near the village of Mukhaialong, which has about 300 households, at an elevation of 1299 m, between 25°39′467″N latitude and 92°26′216″E longitude (Fig. 1). The undulating landscape of the area is interspersed with agricultural fields and coal mines. The field experiment was carried out in Moolawar stream, a small tributary of the Myntdu River, near the village. The stream originates from an elevated area where two small streams (Streams A and B), measuring about 33.0 and 34.0 m, respectively in length, originate from crevices and join together. The two streams differ in certain attributes, which helped in comparing the effectiveness of treatment in the two streams. Details such as length, breadth, bed area, discharge rate etc. of two streams are given in Table 1.The stream water is used for domestic purposes by the villagers, even though it is contaminated with acid mine drainage (AMD) and has a pH of 4.3–5.0. The pH drops further to as low as 3.0–4.0, during the dry season (in winter), when stream flow is severely decreased. The same trend has been observed in other streams of the Jaintia Hills coal mining areas (Chabukdhara and Singh 2016).

Construction of an Open Limestone Channel (OLC)

Open limestone channels were constructed on the two originating Moolawar streams (A and B) using locally available

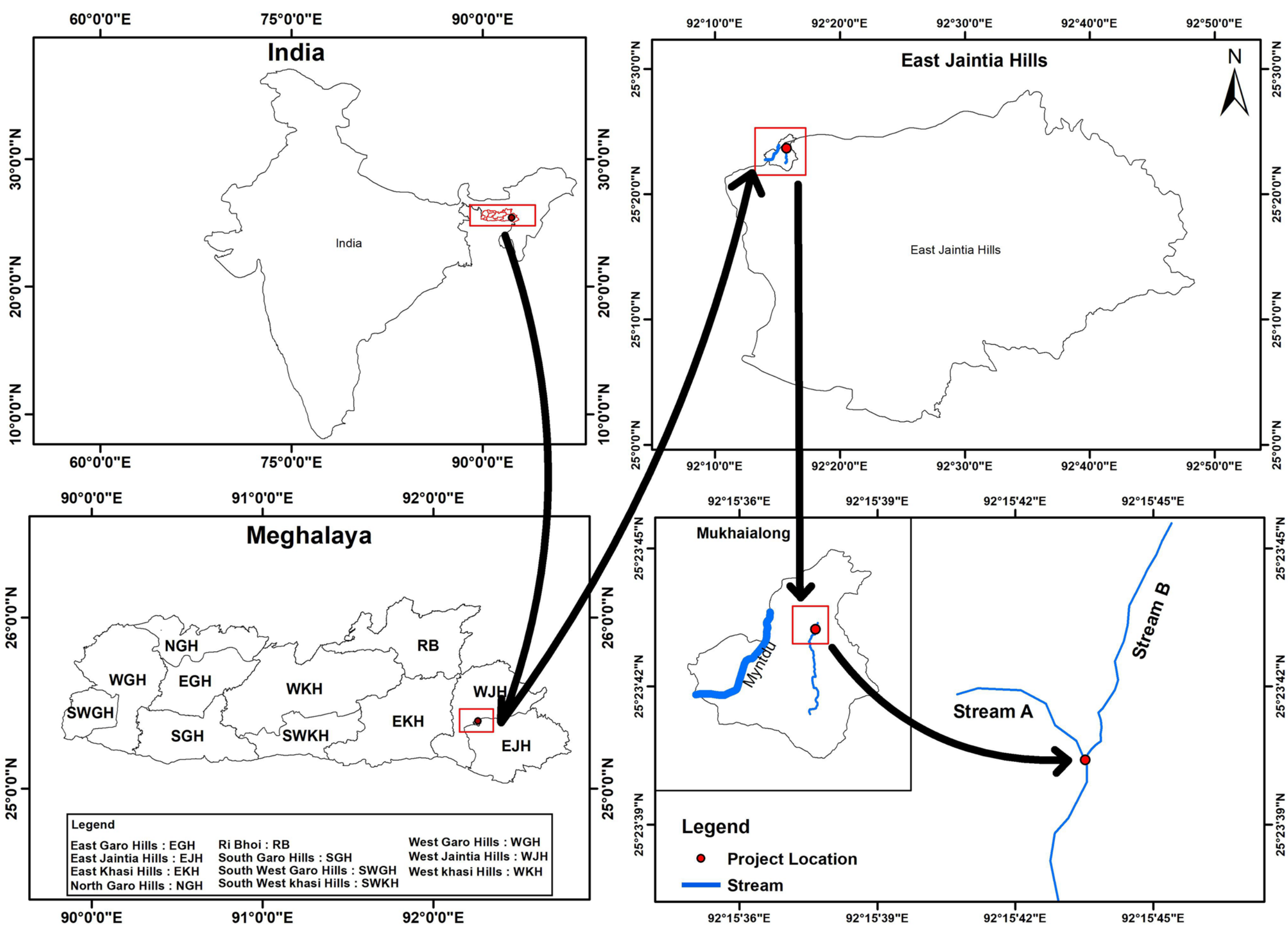

Fig. 1 Location of the experimental site and Moolawar Stream in East Jaintia Hills, Meghalaya

Table 1 Details of Stream A and Stream B and constructed open limestone channels

Particular	Stream A	Stream B
Details of streams		
Length of stream	33.0 m	34.0 m
Width of the stream	0.97 m	1.22 m
Area of the stream bed	12.23 m^2	16.35 m^2
Discharge rate	50.59 L/min	55.60 L/min
Details of open limestone channels		
Height of limestone bed	0.30 m	0.30 m
Total limestone used	11.61 m3	15.18 m^3

limestone. After levelling, the streams were filled with pieces of limestone (measuring about 15–20 cm) to a height of about 30 cm. To prevent downstream sliding of limestone pieces, gabion check dams were constructed about 4.5 m and 9.0 m from the starting point, as shown in Fig. 2. The stream water was channelized through the OLCs so that the acidic water be neutralized by the limestone. The gabion check dam also ensured that the limestone was inundated with the contaminated stream water. Details are given in Table 1.

Physico-Chemical Parameters of the Water

Water samples were collected from two sites at each stream, upstream of the OLC and at its downstream end, at regular intervals starting few days after OLC construction was

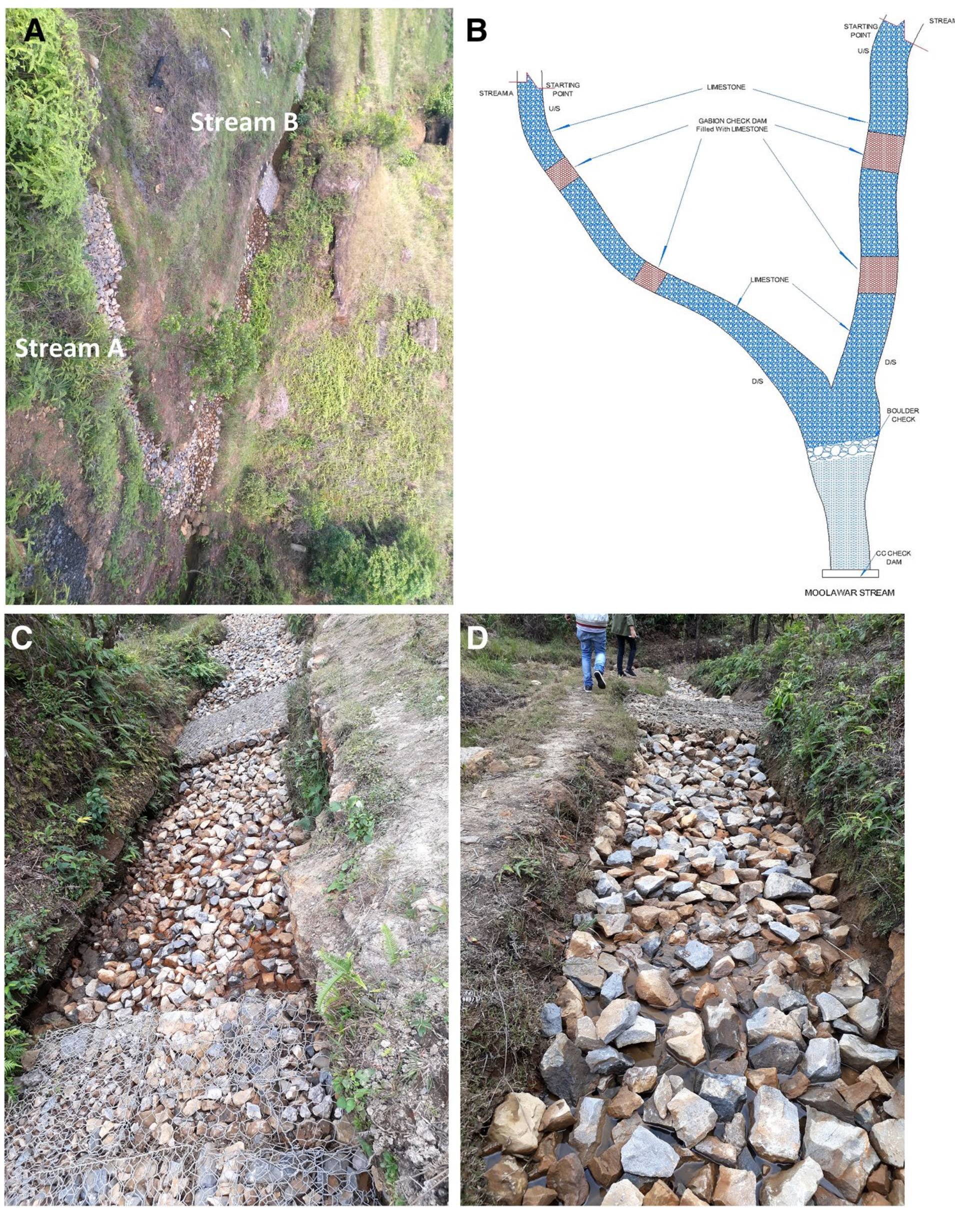

Fig. 2 **a** Photographs showing an aerial view of Moolawar Streams (Streams A and B); **b** diagrammatic representation of the open limestone channel (OLC); **c, d** View of open limestone channels constructed on Moolawar Stream at Mukhaialong Village, East Jaintia Hills District, Meghalaya

completed. The pH was recorded at the experimental sites using a pH meter calibrated to pH 4, 7, and 12 buffers. However, other water quality parameters, such as total dissolved solids (TDS), total hardness (TH), carbonate hardness (CH), non-carbonate hardness (NH), chloride, sulphate, and total iron were analyzed in the Pasteur Institute Laboratory, Meghalaya. Standard methods of sampling and analysis were followed, as described in Maiti (2003) and APHA (2005).

Results

Improvement in Water Quality

The mean values of the various parameters of both streams (A and B) before (Site 1) and after treatment (Site 2) are presented in Table 2. The mean pH of the stream water before entering the OLC was 4.31 and 5.49 in streams A and B, respectively. The pH of the water after passing through the OLC in Stream A increased from 4.31 to 6.57, while in Stream B, the pH increased from 5.49 to 6.32 after passing through the OLC. Based on the pH alone, it is clear that OLC treatment was effective in raising the pH of water (reducing the acidity). The OLC treatment in Stream A was more effective than in Stream B (Table 2).

The total dissolved solids (TDS) was reduced slightly, from 28 to 24 mg/L in stream A by the OLC, while no change was noted in stream B. TH, CH, NH, chloride, iron, and sulphate all showed very little variation before and after treatment. However, the OLC undoubtedly was effective in raising the pH of the stream water.

Ecorestoration of Streams

Along with monitoring of water quality, the stream was monitored for associated changes in its ecology. Before treatment, the stream was almost lifeless with no aquatic insects, frogs, or fish. However, after a few months of continuous treatment, it was noticed that the improvement in water quality paved the way for reappearance of several aquatic species in the treated section of the stream. Species of aquatic insects such as water penny and dragon fly and two fish species appeared. These life forms brought back some activity in the treated section of the stream. Algae growth was also noticed in the treated section. This was an encouraging sign of ecorestoration.

People's Participation

The Mukhaialong community leaders were involved in the OLC construction and operation. Sensitization and awareness meetings were organized with the support of the District Administration, Basin Development Unit (Khliehriat) and the Institute of Natural Resource (INR) under Meghalaya Basin Development Authority (MBDA). The interaction and meetings encouraged villagers to propose a suitable treatment site near the village so that they could use the water for their domestic requirements. Seeing the success and improvement in water quality and restoration of the ecology of Moolawar stream in Mukhaialong village, village communities in other areas of the district have also started replicating the activities of this project in their areas. Based on the demand, the Meghalaya Basin Management Agency has already initiated work to improve the water quality of other AMD affected streams in the Jaintia Hills through an International Fund for Agricultural Development funded project, MLAMP.

Acceptability of the Treated Water

Improvement of water quality and reappearance of some aquatic life in the treated stream section brought a sense of satisfaction among the villagers, leading to higher acceptability of using treated water for domestic use. They also

Table 2 Mean values of various water quality parameters of Stream A and Stream B before (Site 1) and after (Site 2) treatment through the OLC

Water quality parameters	Stream A			Stream B		
	Before treatment (Site 1)	After treatment (Site 2)	Difference	Before treatment (Site 1)	After treatment (Site 2)	Difference
pH	4.31	6.57	2.26	5.49	6.32	0.83
TDS (mg/L)	28	24	−4	22	22	0
Total hardness (mg/L)	7.2	12.6	5.4	12.6	12.6	0
Carbonate hardness (mg/L)	5.4	12.6	7.2	5.4	9.6	4.2
Non-carbonate hardness (mg/L)	1.8	9.6	7.8	7.2	3.6	−3.6
Chloride (mg/L)	10.8	11.8	1.0	11.8	11.8	0
Iron (mg/L)	0.44	0.52	0.08	0.24	0.24	0
Sulphate (mg/L)	4.7	4.1	−0.6	5.7	6.4	−0.7

felt the need to expand such projects in the area so that more streams could be targeted for ecological restoration.

Discussion

Neutralization of Acidic Water in Moolawar Stream

In Meghalaya, the usual pH of surface water is a bit acidic (6.5–7.0) due to pyrite in the soil and rocks (Swer and Singh 2003). Thus, restoring pH of stream water to normal can be considered a success of OLC. However, by doing certain modifications to the OLC's flow rate and gradient, the effectiveness of the treatment can perhaps be enhanced. The better results found in Stream A may be due to relatively gentle slope and lower width and discharge, which allowed longer duration of contact between the acidic water and limestone, facilitating better neutralization.

The OLC is one of the many options available for neutralization of AMD-contaminated acidic water in mining areas. The present study found that the OLC was effective in neutralizing the acidic water. The method is low in cost, easy to operate, eco-friendly, and suitable for rural areas. It not only neutralized the acidity but also improved the aquatic ecosystem downstream. However, to increase the effectiveness of this neutralization, the OLC can also be combined with other passive treatment options, such as constructed wetlands to lower iron concentrations, or other methods of adding alkalinity, such as diversion wells and vertical flow reactors.

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