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International Journal of Current Research
Vol. 4, Issue, 02, pp.002-007, February- 2012

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

IMPACT OF COAL MINE DRAINAGE ON WATER QUALITY AND MICROBIAL ECOLOGY OF STREAMS IN JAINTIA HILLS, MEGHALAYA

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ARTICLE INFO

Article History:
Received 10th October, 2011
Received in revised form
15th November, 2011
Accepted 19th December, 2011
Published online 29th February, 2012

Key words:
Coal mine drainage,
Water quality,
Microbial ecology,
Streams,
Jaintia hills.

ABSTRACT

Accelerated pollution of rivers and streams because of human activity are a concern throughout the world. The objective of this study was to assess the impact of coal mine drainage on streams of Jaintia hills, Meghalaya, India. The water quality status and microbial distribution and diversity of streams were assessed for a period of two years. Diversity indices revealed a decline in terms of microbial abundance and composition. Clustering and ordination analysis clearly separated reference site from coal mine affected sites. Low dissolved oxygen, low pH, high sulphate, iron are some characteristics of coal mine impacted sites. These patterns are the result of a combination of rampant dumping of untreated wastes exacerbated by geologic, topographic, climatic and land use factors.

INTRODUCTION

Meghalaya one of the seven states of northeast India is rich in coal and mineral resources. In Jaintia Hills district of Meghalaya, coal mining activities are small scale ventures controlled by individuals who own the land. Coal extraction is mainly done by primitive mining method commonly known as 'rat-hole' mining which is very crude uneconomical and unscientific. Further, the entire mining area of the Jaintia Hills has become full of mine pits and caves. These open, unfilled pits are the place where surface water percolates and disappears. As a result, small streams and rivers of the area, which serve as lifelines for the people, are either completely disappearing from the face of the earth or becoming seasonal. Consequently, the area is facing acute shortage of clean drinking and irrigation water (Swer and Singh, 2004). The impact of mining activity on a given area is controlled by several factors, including the climate, mining methods, geological conditions, and whether the mine is active or abandoned (Bell *et al*., 2001). In recent years, toxic effects of heavy metals to living organisms, mainly as a result of their continuing anthropogenic mobilization in the environment, have attracted considerable worldwide attention. In contrast to most pollutants, they are not biodegradable, persistent in the environment and aquatic organisms can incorporate these elements directly or indirectly through the food chain (Gadd, 1993). Further, organisms in these environments may be exposed not only to a single chemical but also to a mixture of different substances at the same or nearly the same time, and this can affect biotic communities and ecological processes in a non-predictable way (Duarte *et al*., 2008).

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Heavy metals, can also affect microbial communities by reducing species diversity, and there is a growing concern that accelerating species loss may threaten ecosystem function and services (Schulze and Mooney, 1994; Kinzig *et al*., 2001). A large body of information is available on the large scale destruction of natural forest areas due to mining operations in Jaintia Hills. Most of the studies and data generated for Jaintia Hills have focused on the various aspects of effects of coal mine spoils and coal mining activities on natural vegetations. But, so far data on the occurrence and diversity of microbes in aquatic environment of Jaintia Hills in particular, are virtually, non-existent. Therefore, this study will also provide new information of local environmental problems that would be applicable to developing remediation strategies at a range acidic; heavy metal contaminated waste streams, including coal mining drainage.

MATERIALS AND METHODS

Description of the study area

The study was carried out in the coal mining areas of Jaintia Hills which is situated in the eastern part of the state of Meghalaya and lies between 25°02' N to 25°45'N latitudes; and between 91°58'E to 92°50'E longitudes. The area is bounded in the north and east by the state of Assam; west by East Khasi Hills District of the state and south by Bangladesh. It forms the contiguous part of the Shillong plateau and according to the Census of India, the total population of the district is 295692 and the settlement pattern in the district is mainly compacted or nucleated. Two streams namely Um-Mynkseh (UMR) and Um-Rimet (RR) were chosen from the coal mining areas while Um-Myntdu (MR) which is located

away from the mining area is taken as a reference site. Description of sampling locations is shown in Table 1.

Sample collection and analysis

Water samples were collected in plastic bottles previously cleaned by washing with detergent, thoroughly rinsed with tap water, soaked in 10% HNO_3 solution overnight, and finally rinsed with de-ionized water and dried in an oven. At the sampling sites, sample bottles were rinsed three times with the stream water before filling. Temperature and pH were measured on the field at the time of sampling. Conductivity was measured with the help of a digital conductivity meter. The parameters requiring fresh samples were determined immediately otherwise stored below 4^{o}C until further used. For metal analysis, water samples were collected in 50 ml plastic containers. Water sample were filtered with 0.45 µm filter and acidified with 2 ml concentrated HNO_3. Heavy metal concentrations were analyzed using Atomic Absorption Spectrophotometer method (Model Perkin-Elmer 3110). The experimental methods for other parameters such as dissolved oxygen, sulphate, phosphate, chloride, ammonia, nitrate, magnesium, and calcium are carried out as outlined in Standard methods for examination of water and waste water (APHA, 1998). The datas are then compared with standard water quality guidelines given by the Bureau of Indian Standards (1991) and World Health Organisations (2006). Isolation and counting of microorganisms was done using plating technique of APHA 1998. Malt extract agar medium and Standard plate count agar medium was used for isolation of fungi and bacteria respectively. The inoculated Petri-plates are then incubated at 25± ºC at 5-7 days for fungi and 30±1 ºC at 24- 48 h for bacteria respectively. After incubation the colonies were expressed as colony forming units per ml.

Statistical analysis

Statistical analysis of the results at each site was carried out using both XLSTATS 2009 and Statsoft 6.0, for windows software. Relationships between the various physico-chemical parameters, fungal and bacterial species diversity were assessed using Pearson's correlation coefficient analysis. The different indices were calculated using Past 2009 software. All errors were calculated at the 95% confidence level. The significance for the mean of the different parameters within sites as compared to the reference and among them was done with one-way ANOVA.

RESULTS AND DISCUSSION

Physicochemical characteristics of stream water at the sampling sites

The range, mean and standard deviation of pH, conductivity and dissolved ion concentration for the samples collected from the three study sites of Jaintia Hills District are given in Table 2. Water pH varied from circumneutral in the reference site to highly acidic in the streams of coal mining areas. The minimum pH of 1.9 was recorded from site UMR and a maximum of 7.5 was recorded from site MR. There was a significant variation (p<0.05) of pH in between the three study sites, although there was no clear trend of seasonal variation between them. The pH range for waters in the streams of coal mining areas has been found to be lower than the prescribed range of 6.5 -8.5 for domestic use by WHO (2006) and this can be directly linked to the acidic drainage from mines and spoils which seep into the water bodies, as many open shafts and rat hole mines are present near the streams (Cherry *et al*., 2001). Conductivity for all the three study sites was significantly different (p<0.05). It ranges from 0.05 to 3.63 mS/cm in the streams of coal mining areas and 0 to 0.14 mS/cm in the reference site. Since elevated conductivity is commonly associated with mining activities, as reported earlier, it has proven to be an excellent indicator of mining related influences (Soucek *et al*., 2000; Kennedy *et al*., 2003). The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L, respectively (BIS, 1991). In our study, calcium and magnesium content ranges from 10.22 to 60.60 mg/l and 8.00 to 173.00 mg/l respectively. Calcium was higher in streams of coal mining areas while magnesium was higher in the reference site. Calcium and magnesium hardness varied significantly (p<0.05) between the three study sites. MR varied significantly with both UMR and RR (p<0.05), however there was no significant variation between UMR and RR. Higher calcium concentration has also been reported by Cidu (2007) in surface waters impacted by past mining at Funtana Raminosa (Sardinia). Magnesium content in the reference site has exceeded the prescribed limit of both BIS and WHO, and this could be attributed to run off or leacheate of fertilizers from nearby paddy field.

Although mine drainage may contain elevated concentrations of Fe, Mn, and Al, these elements usually are not reliable indicators of coal or acid mine drainage as they may not remain in solution. Sulphate, however, is an excellent indicator of mine drainage because the sulphate ion is highly soluble and chemically stable at the pH levels normally encountered in waters (James *et al*., 2000). Sulphate concentration varied from 4.51 to 25.80 mg/l in site MR, while in streams of coal mining areas it ranged from 205.50 to 637 mg/l which was well above the prescribed range given by WHO (2006). There was a significant variation (p<0.05) of sulphate among the study sites and between the streams of coal mining areas. Chloride content in UMR and RR ranged from 7.40 to 37.70 mg/l while in MR it ranged from 2.40 to 13.80 mg/l. There was a significant variation (p<0.05) between chloride concentrations in all the three study sites. Although chloride concentration was more in streams of coal mining areas concentration in all the three samples were lower than the permissible limit of 250 mg/l (BIS, 1991; WHO, 2006). This is in conformity with Brake *et al*. (2001) who conducted the study on the impact of mine drainage on the geochemistry of West Sugar Creek pre- and post reclamation at the green valley coal mine in Indiana, USA. Different patterns of ionic dominance were observed in the streams affected by coal mine drainage and that of the reference site. Water samples from UMR and RR has the same ionic dominance pattern of sulphate>calcium>magnesium>chloride. Ionic dominance in MR site was magnesium> calcium>sulfate>chloride. The dominance of chloride over sulphate in reference site was mainly due to domestic and anthropogenic point sources (Karikari and Ansa-Asare, 2006) while, the dominance of sulphate over the other ions in affected streams could be ascribed to the presence of iron sulphide which on oxidation releases sulphate ions in water bodies of the mining area (Swer and Singh, 2004).

Table 1. Name of sampling sites, sampling collection streams and their geographical locations

Location	Study Site	Sample site code	GPS Reading
Jowai	Um-Myntdu	MR	N 25°27.128' E 090° 11.475'
Khliehriat	Um-Mynkseh	UMR	N 25°22.436' E 090° 20.360'
West Dkhiah	Um-Rimet	RR	N 25°21.702' E 092° 20.495'

Table 2. Range, mean and standard deviation of ph, conductivity and dissolved ion concentration of the samples during the sampling period

Sites/ Parameters	pH	Conductivity (mS/cm)	Magnesium (mg/l)	Calcium (mg/l)	Sulphate (mg/l)	Chloride (mg/l)
MR: Range	6.03-7.50	0.00-0.10	20.02-173.00	10.80-43.20	4.51-25.80	2.40-13.80
Mean ± SD	6.70 ± 0.38	0.04 ± 0.03	74.08 ± 37.34	27.70 ± 10.14	12.53 ± 4.48	6.38 ± 3.16
UMR: Range	1.90-3.20	0.30-3.63	9.00-45.30	10.22-52.00	322.70-637.10	15.30-37.70
Mean ± SD	2.49 ± 0.36	1.65 ± 0.00	24.25 ± 11.47	35.01 ± 10.28	492.43 ± 94.31	22.39 ± 5.59
RR: Range	2.20-4.06	0.05-1.19	8.00-44.12	13.60-60.60	205.54-401.50	7.40-23.90
Mean ± SD	3.11 ± 0.52	0.67 ± 0.32	21.36 ± 10.94	35.55 ± 11.98	300.30 ± 66.89	13.94 ± 4.16
WHO	6.5-8.5	250	30	75	250	250
BIS	6.5-8.5	250	30	75	250	250

Table 3. Range, mean and standard deviation of nutrients and dissolved oxygen concentration of the samples during the sampling period

Sites/ Parameters	DO (mg/l)	NH_4-N (mg/l)	NO_3-N (mg/l)	PO_4 (mg/l)
MR: Range	6.50-12.10	0.09-0.21	0-0.9	0.26-2.29
Mean ± SD	10.00 ± 1.20	0.14 ± 0.03	0.12 ± 0.05	1.19 ± 0.49
UMR: Range	3.50-6.03	0.10-0.33	0.14-0.98	1.32-4.18
Mean ± SD	4.79 ± 0.67	0.19 ± 0.06	0.40 ± 0.23	2.35 ± 0.91
RR: Range	4.80-7.06	0.16-0.39	0.02-0.9	1.14-4.28
Mean ± SD	5.72 ± 0.68	0.27 ± 0.06	0.28 ± 0.19	2.43 ± 0.89
WHO	-	<45	<45	<0.3
BIS	-	<45	<45	<0.3

Table 4. Range, mean and standard deviation of dissolved metals and trace elements concentration of the samples during the sampling period

Sites/Parameters	Fe (mg/l)	Cu (mg/l)	Cd (mg/l)	Zn (mg/l)
MR: Range	0-0.26	0-0.08	0-0.03	0-0.08
Mean ± SD	0.09 ± 0.11	0.02 ± 0.02	0.01 ± 0.00	0.04 ± 0.03
UMR: Range	10.80-30.24	0.02-0.22	0.02-0.19	0.08-1.67
Mean ± SD	20.91 ± 5.33	0.12 ± 0.04	0.06 ± 0.05	0.70 ± 0.43
RR: Range	3.66-16.68	0-0.18	0-0.20	0.01-1.14
Mean ± SD	12.52 ± 2.70	0.09 ± 0.06	0.04 ± 0.04	0.31 ± 0.26
WHO	0.3	2	0.003	3
BIS	0.3	0.05	0.01	5

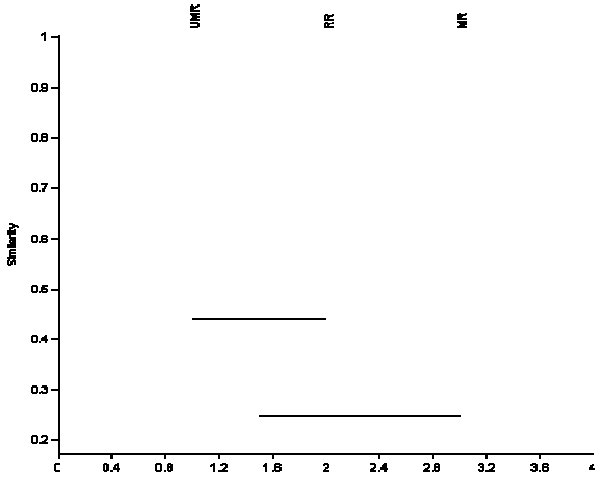

Fig. 1. Hierarchal clustering (using group average linking) of three sampling sites showing separate clustering of MR based on the relationship of sampling sites and fungal diversity

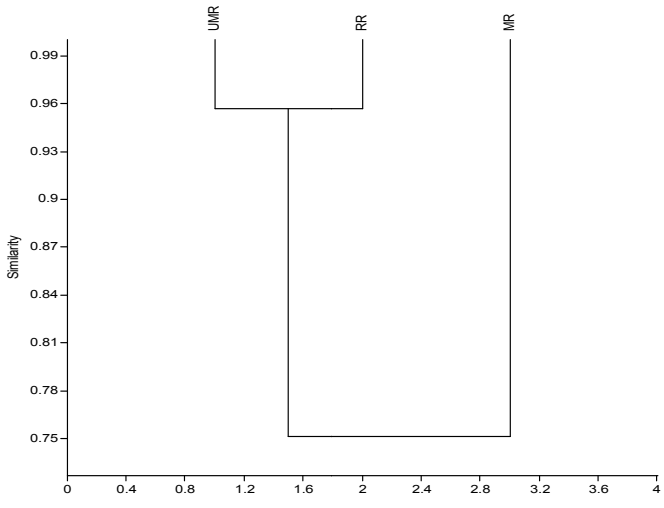

Fig. 2. Hierarchal clustering (using group average linking) of three sampling sites showing separate clustering of MR based on the relationship of sampling sites and bacterial diversity

Table 5. Distribution of fungi at different sites during the sampling period

Sl no.	Fungal species	MR	UMR	RR
1	*Absidia spinosa* Lendn.	+	-	-
2	*Achlya* sp	+	-	-
3	*Acremonium butyri* (van Beyma) W. Gams	-	+	+
4	*A. cerealis* (Karst.) W. Gams	+	-	-
5	*A. fuscidioides* (Nicot) W. Gams	+	-	-
6	*A. kiliense* Grütz	+	-	-
7	*A. strictum* W. Gams	+	-	-
8	*Alternaria alternata* (Fr.) Keissler	-	+	+
9	*A. longipes* (Ellis & Everhart) Mason	+	-	+
10	*A. macrospora* Zimm.	+	-	-
11	*Aspergillus flavus* Link ex Gray	+	-	+
12	*A. fumigatus* Fres.	+	+	+
13	*A. japonicus* Saito	+	-	-
14	*A. niger* van Tieghem	+	+	+
15	*A. sydowii* (Bainier & Sartory) Thom & Church	+	+	+
16	*A. terreus* Thom	+	-	-
17	*A. ustus* (Bainier) Thom & Church	+	-	+
18	*A. vesicolar* (Vuill.) Tiraboschi	+	-	-
19	*Aureobasidium pollullans* de Hoog & Gunde-Cimerman	+	+	-
20	*Broomella acuta* Shoemaker & E. Müll.	+	-	-
21	*Candida* sp	+	+	+
22	*Chaetomium nozdrenkoae* Sergeeva	+	-	+
23	*Chloridium* sp	-	-	+
24	*Cladosporium herbarum* (Pers.) Link ex Gray	+	+	+
25	*C. sphaerospermum* Penz. 1882	-	+	-
26	*Cryptococcus humicola* (Dasz.) Gobulev	-	+	+
27	*C. laurentii* (Kuff.) C.E. Skinner	-	+	-
28	*Exophalia jeanselmei*	-	-	+
29	*Helicosporium* sp	-	+	-
30	*Humicola fuscoatra* Traaen	+	-	-
31	*H. grisea* Traaen	+	+	+
32	*Ingoldia* sp	+	-	-
33	*Monilia* sp	-	-	+
34	*Mortierella vinaceae* Dixon-Stewart	-	-	+
35	*Mucor hiemalis f. corticola* (Hagem) Schipper	+	+	-
36	*M. hiemalis f. silvaticus* Wehmer	-	-	+
37	*Myrothecium verrucaria* (Alb. & Schwein.) Ditmar	+	-	+
38	*Nectria ventricosa* C. Booth	+	-	-
39	*Oidiodendron griseum* Robak	+	+	+
40	*O. truncatum* G.L. Barron	+	+	+
41	*Paecilomyces* sp	-	-	+
42	*Penicillium chrysogenum* Thom	+	+	-
43	*P. digitatum* (Pers.) Sacc	+	-	-
44	*P. expansum* Link ex Gray	+	+	+
45	*P. frequentans* Westling	-	+	+
46	*P. italicum* Wehmer	+	-	-
47	*P. janthinellum* Biourge	+	+	-
48	*P. jensenii* Zaleski	+	-	-
49	*P. lanosum* Westling	+	-	-
50	*P. nigricans* Bain. Ex Thom	+	-	-
51	*P. purpurogenum* Stoll	+	+	-
52	*P. restrictum* Gilman & Abbott	-	-	+
53	*P. rubrum* Stoll	+	-	+
54	*P. simplicissimum* (Oudem.) Thom	+	+	+
55	*P. stoloniferum* Thom	-	-	+
56	*P. variable* Sopp.	+	-	-
57	*Phialophora fastigiata* (Lagerb. & Melin) Conant	+	+	+
58	*Phoma eupyrena* Sacc.	+	-	-
59	*Phoma* sp	+	-	-
60	*Pythium aphanidermatum* (Edson) Fitzp.	+	-	+
61	*P. intermedium* de Bary	+	-	-
62	*P. irregulare* Buisman	+	+	-
63	*Pythium* sp	-	-	-
64	*Rhizopus stolonifer* (Ehrenb. Ex Link) Lind	+	+	+
65	*Rhodotorula aurantiaca* (Saito) Lodder	-	+	+
66	*R. mucilaginosa* (A. Jorg)	-	-	+
67	*Saccharomyces cerevisiae* Meyen ex E.C. Hansen	+	+	-
68	*Staphylotrichum coccosporum* J.A. Mey. & Nicot	+	-	+
69	*Talaromyces emersoni* Stolk	+	-	-
70	*T. helicus* (Raper & Fennell) C.R. Benj.	+	-	-
71	*T. trachyspermus* (Shear) Stolk & Samson	-	-	+
72	*T. wortmanii* (Klocker) C.R. Banjamin	+	-	-
73	*Trichoderma harzianum* Rifai	+	-	-
74	*T. koningii* Oudem.	+	+	+
75	*T. polysporum* (Link ex Pers.) Rifai	-	-	+
76	*T. pseudokoningii* Rifai	+	-	-
77	*T. viride* Pers. ex Gray	+	-	+
78	*Trichosporon dulcitum* (Berkhout) Weijman	-	-	+
79	*Verticillium alboatrum* Reinke & Berthold	+	-	-
80	*V. nigrescens* Pethybr.	-	-	+
81	white sterile mycelium	+	-	-

Table 6. List of bacteria isolated from the three different sites during the study period

Sl.No	Bacteria identified	MR	UMR	RR
1	*Acidiphilum* sp	-	-	+
2	*Aerobacter* sp	+	-	+
3	*Bacillus cereus*	+	+	+
4	*Bacillus mycoides*	+	+	+
5	*Bacillus* sp	+	+	+
6	*Bacillus subtilis*	+	+	+
7	*Chromatium* sp	+	-	+
8	*Chromobacterium* sp	+	+	+
9	*Escherichia coli*	+	+	-
10	*Flavobacterium* sp	+	+	+
11	*Lactobacillus* sp	+	+	+
12	*Micrococcus* sp	-	+	+
13	*Proteus vulgaris*	+	-	-
14	*Pseudomonas* sp	+	+	+
15	*Staphyllococus aureus*	+	+	+

Table 7. Diversity Indices of fungi and bacteria at different sites during the sampling period

	Indices	MR	UMR	RR
Fungi	Species richness	61	33	41
	Shannon *H*	2.0	0.94	1.29
	Simpson *D*	0.17	0.42	0.39
	Berger-Parker	1.02	0.91	0.8
Bacteria	Species richness	12	9	8
	Shannon *H*	1.29	0.76	0.78
	Simpson *D*	0.32	0.54	0.50
	Berger-Parker	1.12	0.51	0.48

Concentrations of nutrients and dissolved oxygen (DO) are shown in Table 3. DO show a significant variation ($p<0.05$) between the three study sites, also site MR varied significantly with both UMR and RR ($p<0.05$). DO concentration is lowest in UMR with a mean value of 3.50 mg/l and highest at MR with a mean value of 12.10 mg/l. The low DO values in the streams of coal mining areas might be attributed to the fact that the waste discharge within the watershed contains high concentration of organic matter and nutrients that are highly oxygen demanding (Chapman, 1996; Lee *et al*., 2005). NO_3–N and NH_4–N are considered to be non-cumulative toxins (Dallas and Day, 1993). Although a prescribed limit of 45 mg/l has been described by both WHO and BIS, high concentrations of NO_3–N could be of potential health risks, particularly in pregnant women and infants under 6 years of age (Kempster *et al*., 1997). The streams in both the coal mining and reference sites recorded NO_3–N and NH_4–N concentrations lower than the WHO permissible limit for

drinking water. All the values for phosphate were above the WHO recommended levels of less than 0.3 mg/l with the maximum value (4.28 mg/l) being recorded in UMR and the minimum (0.26 mg/l) in MR. Reference site shows no significant variation (p<0.05) with both the streams in coal mining areas and no significant variation (p<0.05) was recorded between the latter. The high phosphate levels in all the streams may have come from small-scale farming activities observed along the banks of the streams (Sharpley *et al*., 1987). The levels of phosphate in the streams suggest that the untreated water could not be recommended for drinking and other domestic purposes. The contamination of water bodies by heavy metals during mining is of great concern due to their toxicity and accumulative behaviour. The concentrations of different dissolved metals are shown in Table 4. The concentration of Fe in samples from the streams of coal mining areas varies from 3.66 to 30.24 mg/l and 0 to 0.26 mg/l in the reference site. It is evident from the results that the water samples from the reference site fall between the permissible limit of 0.3 mg/l, however, samples from the streams of coal mining areas exceeds the permissible limit of both WHO and BIS. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. The weathering of rock and discharge of waste effluents on land are generally considered the main source of iron in ground water.

The distribution of Cu at the two streams in coal mining sites ranged from 0 to 0.22 mg/l whereas in reference site it is 0 to 0.08 mg/l. In the study area, all the samples fall below the desirable and permissible limit of both BIS (1991) and WHO (2006). Cd which is a non-essential, non-beneficial element known to have a high toxic potential can enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. In our study, Cd ranges from 0 to 0.19 mg/l in UMR and RR, while in MR it ranges from 0 to 0.03mg/l. The streams of coal mining areas have exceeded the limit prescribed by both BIS and WHO. The values in MR are well within the limit prescribed by BIS (1991) although it has exceeded the limit given by WHO (2006). The distribution of Zn at UMR and RR sites ranges from 0.01 mg/l to 1.67 mg/l while, in MR it ranges from 0 mg/l to 0.08 mg/l. BIS (1991) has prescribed 5 mg/l Zn as the desirable permissible limit for drinking water whereas WHO (2006) has prescribed 3 mg/l as the guideline value for drinking water. The water samples from all the three sites were within the desirable limit prescribed by BIS and WHO. Of all the elements investigated, Fe concentrations were found to be the highest at each location. The concentration of the metals in water bodies of coal mining areas indicate that Fe and Cd were above the typical background levels for waters, while, concentrations of dissolved metals in reference site were relatively low and were all below the guidelines established by BIS (1991) and WHO (2006). These findings are in agreement to those earlier reports (Swer and Singh, 2005).

Microbial (Fungal and bacterial community) indices

81 species of fungi were isolated of which 12 species were found to be common to UMR, RR and MR site, while 3 species were found to be present only in UMR and RR (Table 5). A total of 15 species of bacteria were isolated of which 9 were found to be common to UMR, RR and MR site, while 2 were found to be present only in UMR and RR. List of bacteria isolated were given in Table 6. Of all the bacteria isolated *Acidiphillium* sp. and *Micrococcus* sp. has been isolated only from the coal mining sites, while Proteus sp has been isolated only from MR. Diversity index of fungi and bacteria were given in Table 7.Shannon diversity index (*H'*) and species richness of fungi was significantly higher (p<0.05) at site MR followed by streams affected by coal mine drainage i.e. RR and UMR. Simpson's Index (D), which measures the probability that two individuals randomly selected from a sample will belong to the same species accounts for both abundance and evenness of the species present. The value of D ranges between 0 and 1 and with this index, 0 represents infinite diversity and 1, no diversity (Strong, 2002). This index was relatively higher at the coal mining sampling sites UMR and RR. Berger- Parker dominance index was also higher in reference site. All metrics reflect the same in that sampling site MR was the best in both abundance and evenness and the sampling sites UMR and RR which were affected by coal mine drainage were dominated by related species and poor in diversity.

Multivariate classification of fungi, bacteria and environmental characteristics

The multivariate classification of the sampling sites based on the biological data for the sampling site is illustrated in Fig. 1-2. They clearly demonstrate that the reference site MR was unique among sampling sites. Coal mine drainage impacted sites (UMR, RR) are similar in their microbial communities and sampling sites have been grouped together.

Conclusion and Recommendations

It is evident from the analysis of the different parameters that the water quality of UMR and RR are deteriorating due to coal mine drainage which found their way into the streams. The pollution level in some of them has reached the toxic level, making their waters unfit for human use. This can also be indicated by the decline of fungal and bacterial species diversity when compared to the reference site. The rapid and unscientific mining activities in and around the streams of Jaintia Hills, the corresponding rise of untreated mine wastes which flows into the water bodies, the streams and also rivers may be subjected to even more pronounced effects than those described in this study, limiting their future use for domestic, recreational, agricultural and industrial purposes. Any remediation efforts will have to consider the implementation of anti-pollution measures in the form of solid waste disposal at designated sites away from water courses and slopes, and the development of educational programs aimed at raising awareness of the pollution problem and the need for its prevention. Our findings suggest that further studies characterizing the streams in the polluted sites and a more detail study on microbial taxa may help to develop scientific criteria for pollution monitoring and in developing remediation strategies in the coal mine affected sites.

Acknowledgements

The authors are grateful to Head, Department of Botany, for providing laboratory facilities. The first author is also grateful

to the Ministry of Environment and Forests, Government of India, New Delhi, for financial support in the form of research fellowship.

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