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Water Characterisation of Coal Mining Areas of Chakwal, Punjab, Pakistan

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Abstract. Discharged water from mines shows alteration in its physical properties and may be acidic depending upon the concentration of heavy metals and sulphate ions, which pose hazardous effects on groundwater and ecosystem. This paper deals with the characterisation of water being affected by coal mining in the Basharat area of Punjab. Total eleven samples were collected from different water sources including groundwater, mine outflows, mine inflows and surface water in the vicinity of Hassan Kishor Coal Mine. All samples except that of groundwater showed higher turbidity, lower pH values and higher total solid contents. Higher concentration of iron and copper in all samples indicate higher acid mine drainage (AMD). Relatively larger concentration of calcium in groundwater as compared to its presence in other samples demonstrates quashing effect of overlying limestone to the AMD.

Keywords: water pollution, groundwater, coal mine, acid mine drainage

Introduction

The rapid growth of population particularly in developing countries such as Pakistan demands more natural resources for the fulfillment of needs of human beings. These large quantities of natural resources are obtained through increased mining activities and amplified rate of extraction. The growing mining activities are vigorously endangering the environment (Monjezi *et al*., 2009). Mining adversely affects the environment during all of its stages even after the completion of mining operation (Singh *et al*., 2011; Younger *et al*., 2002). Its major negative impacts include changes in hydrology, lithology, topography, ecology, land-use distribution and visual degradation, socio-economic statistics and atmosphere (Singh, 2008). Probably the most severe damage occurs to the groundwater regime of the area. Generally, water is contaminated either physically or chemically by taking up impurities. This contaminated water enteres the water cycle and causes hazardous effects on living things, land and atmosphere. Extent of water contamination is primarily dependent upon composition of ore deposits and its surrounding geology, structural features of the area, hydrology and climate of the mining region (Dold and Fontbote, 2001).

Coal mining adversely affects the hydrology of the area. Acid generation through oxidation of sulphur-bearing minerals such as pyrite in coal mines is one of the major causes of water contamination (Tiwary, 2000). The amount of acidity produced from a coal mine mostly depends on the sulphide contents, age of the deposit, alkalinity producing minerals and waste volumes (Gomes *et al*., 2011). Manganese, iron and aluminium are found to be the major elements, which constitute acidity in coal mine drainages (Skousen *et al*., 1998). Normally sulphide minerals react with oxygen and water to produce sulphuric acid and iron sulphide or iron hydroxide. Reaction of pyrite with oxygen and water is discussed by many researchers (Banks *et al*., 1997; Zaihua *et al*., 1991; Powell, 1988). The reduced pH values cause further dissolution of various minerals and toxic metals into water (Tiwary, 2000). Lead, arsenic and nickel are frequently found toxic metals in coal mine drainages (Younger and Sapsford, 2004).

The aquatic life is adversely affected by the acid-generation. Not only the lower pH values harm organisms but release of heavy metals into water severely damages the aquatic biota, wild life and land fertility for vegetation (Tiwary, 2000). Besides, acid mine drainage in appropriate physical conditions like temperature and turbidity of water play significant role in limiting the growth of living things (Kumar and Kakrani, 2000). This study aims to physically and chemically characterise water samples collected from different sources in and around coal mines in Basharat area, Punjab. These samples

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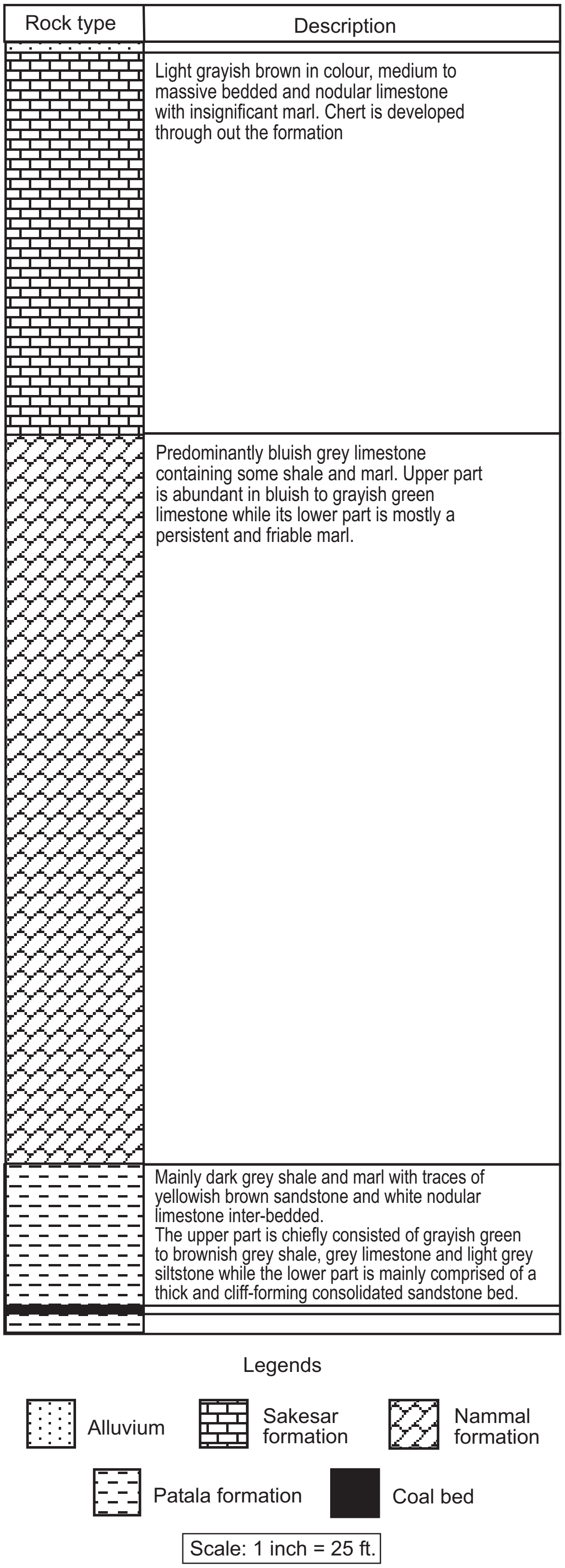
Materials and Methods

Location and geology of the study area. Water samples were collected from different sources in and around of Hassan Kishor Coal Mine situated in Basharat area which is 17 km north-east of Choa Saiden Shah and 40 km south-east of Chakwal (Fig. 1). The stratigraphic sequence of the area is given in the Fig. 2.

Sample collection. Total eleven water samples were collected in pre-cleaned air tight bottles washed by nitric acid prior to sampling from different sources including mine inflows (I1 and I2), mine outflows (O1, O2, O3), groundwater outlets (G1, G2) and surface flows (S1, S2, S3) and labeled as shown in Fig. 3.

Each sample from a particular source was collected from different locations. I1 and I2 were collected from two different points within the mine, while I3 was sampled from a little inrush of water in the midway of the main incline. O1, O2 and O3 were collected from

Fig. 1. Location map of Hassan Kishor Coal Mine. (www.maps.google.com).



Light grayish brown in colour, medium to massive bedded and nodular limestone with insignificant marl. Chert is developed through out the formation

Predominantly bluish grey limestone containing some shale and marl. Upper part is abundant in bluish to grayish green limestone while its lower part is mostly a persistent and friable marl.

Mainly dark grey shale and marl with traces of yellowish brown sandstone and white nodular limestone inter-bedded.
The upper part is chiefly consisted of grayish green to brownish grey shale, grey limestone and light grey siltstone while the lower part is mainly comprised of a thick and cliff-forming consolidated sandstone bed.

Fig. 2. Stratigraphic sequence of the study area (Ibrahim, 2009).

Fig. 3. Water samples collected from Basharat area near Hassan Kishor Coal Mine.

sump-1 situated down the main incline, discharged water by pump and sump-2 located in midway of the incline, respectively. G1 was collected from a well nearby the mine portal while G2 was sampled from a well far away from mine. S1, S2 and S3 were collected from three different surface sources located in different directions to the mine. In order to find out the potential of coal to pollute water, a sample C1 was prepared in the laboratory by adding 7 liter distilled water in 2 kg crushed coal having particle size less than 4 mm. The mixture was allowed for 24 h and then the polluted water was filtrated through a 150 micron sieve to get the desired water sample.

Methodology. Colour of all water samples was noted before and after exposure of 24 h to fresh air to get an idea of oxidation (Fig. 4).

Mercury thermometer calibrated in degree Celsius was used to measure temperature of the water samples on-site. pH and turbidity (haziness of a fluid due to invisible suspended particles) of all samples were measured by using ELE pH meter and ELE turbidity meter, respectively. The Lovibond SesnsoDirect Con200 electrical conductivity meter was used to determine the electrical conductivity of water samples in µS and mS (micro and milli Siemens). Total solid (TS) and total dissolved solids (TDS) were determined by using conventional heating methods. ELE Paqualab Photometer was utilized to find out concentrations of metals such as calcium, magnesium, zinc, and copper as well as sulphate ions.

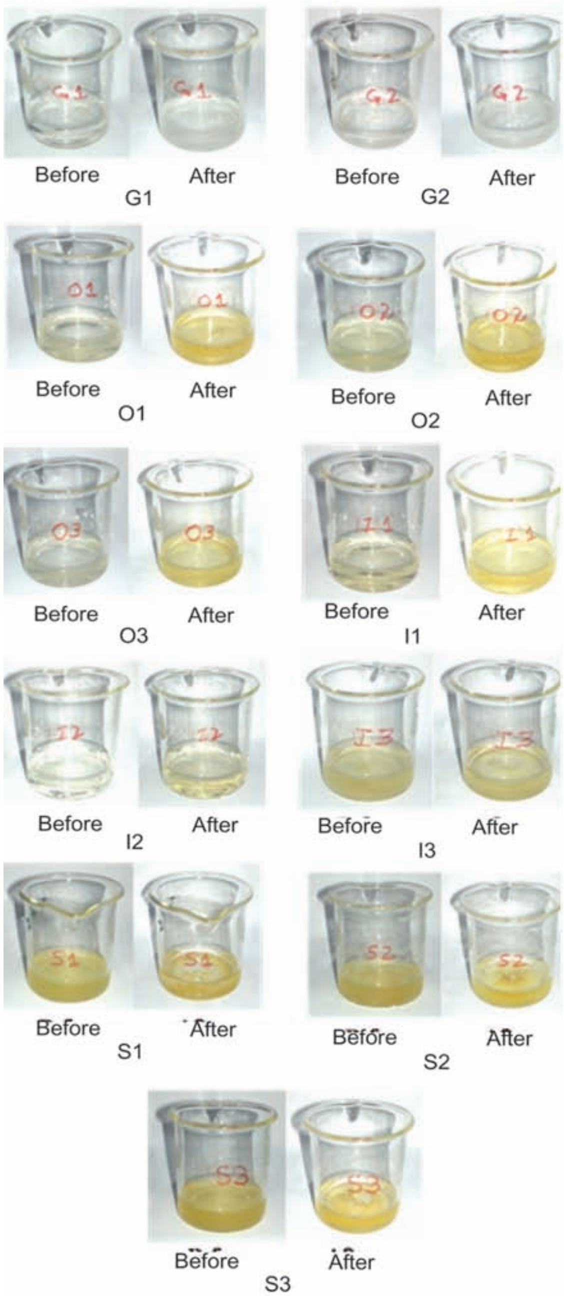


Fig. 4. Colour of the water samples before and after one day exposure to fresh air.

Iron concentration was estimated indirectly by using following stoichiometric relation (Younger *et al*., 2002) assuming that pyrite content (FeS_2) is the only source of sulphate and iron ion production in coal mines.

$$2FeS_2(s) + 7O_2 + 2H_2O \rightarrow 2Fe^{+2} + 4SO_4^{-2} + 4H^+$$

Results and Discussion

Groundwater samples showed a slight increase in turbidity while a dramatic increase in turbidity was

Table 1. Characteristics of water samples collected from in and around the vicinity of Hassan Kishor coal mine

Sample	Temperature	pH	Conductivity	Turbidity	Concentrations (mg/L)							
limit**	(°C) (on-site)	6-9	(mS)	(ftu)	Total solids	TDS	Ca	Mg	Fe*	Zn	Cu	SO_4^{2-}
	---		---	5	(200***+3500)	3500	--	--	8.0	5.0	1.0	600
G1	16	6.35	7.72	1.151	530	460	153	1.0	60	0.00	1.28	207
G2	16	6.46	7.33	1.152	760	530	415	7.0	60	0.00	0.72	207
O1	21	2.23	66	4.85	6530	5130	14	12.5	63	0.11	11.75	215
O2	21	2.31	67	4.77	6800	4500	14	5.0	60	0.06	11.75	207
O3	21	2.31	71	4.7	5730	5000	0	0	63	0.08	10.53	215
I1	23	2.27	20.37	5.12	5060	4500	56	0	63	0.03	10.53	215
I2	23	2.32	6.64	5.29	6130	4500	56	0	63	0.01	10.53	215
I3	17	6.29	403	0.882	830	460	0	6.0	74	0.50	4.48	254
S1	19	2.36	396	2.76	3260	2200	0	5.0	80	0.97	7.58	267
S2	19	2.34	493	2.82	3200	2460	0	7.0	74	1.13	6.91	254
S3	19	2.43	592	2.87	3530	1730	0	10.0	74	0.86	7.22	254
C1	22	5.63	412	1.039	2630	860	0	12.5	88	0.03	11.75	302

* = iron concentration is calculated from sulphate ion concentrations by using stoichiometric relation assuming that pyrite is the only source of iron and sulphate ions; ** = after national environmental quality standards (NEQS, 1997); *** = total suspended solid limit.

observed for the samples of mine outflows, surface water and mine inflows. All samples except groundwater showed yellow coloured precipitates after exposure of 24 h to fresh air. The yellowish colour of water is likely due to the formation of iron hydroxide [$Fe(OH)_3$], which is commonly found in the water bodies near coal mining areas. Generally, when iron is introduced into the natural water, it becomes hydrolysed and forms precipitate of iron hydroxide. Iron in coal mines normally results from pyrite contents in the coal (Sewer and Singh, 2004).

The results of temperature, pH, turbidity, total solids, total dissolved solids, and metal, and sulphate concentrations are shown in the Table 1. pH values of the water samples vary between 2.27 and 6.46. All samples except that of groundwater showed low pH values which indicate acidity of the water. This water may flow to rivers or streams where it can be hazardous to aquatic life since it facilitates leaching of toxic metals into the water (Sewer and Singh, 2004). Moreover, high acidity limits the amount of nutrients in the water which usually are required for vegetation (Ezeigbo and Ezeanyim, 1993).

The analysis of mine outflows and inflows revealed higher total solid (TS) and total dissolved solid (TDS) beyond the standard limits (NEQS, 1997). These solid materials may be present in the form of insoluble suspended mineral particles and soluble ions of metals and sulphate. The suspended particles are harmful for aquatic life as they reduce the availability of light and dissolved oxygen in water which is necessary for photosynthesis.

Although sulphate ions in all water samples are found to be within limits which vary between 207 and 302 mg/L, they may combine with water to form sulphuric acid or can attach to calcium ions to form gypsum sludge. Copper and iron concentrations vary from 0.72 to 11.75 mg/L and 60 to 88 mg/L, respectively. These concentrations are very high which are responsible for acidity of water. Concentration of calcium, magnesium and zinc vary from 0 to 415, 0 to 12.5 and 0 to 1.13 mg/L, respectively. Higher concentration of calcium and magnesium are the root causes of water hardness which may affect health of living bodies if used for drinking purposes.

Conclusion

Most of the water samples were found to be severely affected by impurities. These impurities appeared in the form of suspended and dissolved solids. Elevated concentrations of iron, copper and sulphate in most of the water samples had caused considerable reduction in pH value of water making it highly acidic. However, it was found that groundwater was not much affected yet as it showed the pH value in the prescribed safe limits (6-9). It was concluded that geological formations such as limestone present in the study area is natural treatment process of the mine discharged water. This was confirmed by the presence of large amount of calcium ions and relatively low concentrations of iron, copper and sulphate ions in the groundwater samples. Moreover, characteristics of the water extracted from coal samples in the laboratory clearly revealed that the coal seam had fair tendency to produce acid mine water.

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