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STUDIES ON WATER QUALITY PARAMETERS AT MIDDLE REACHES OF DIKHOW RIVER OF ASSAM WITH REFERENCE TO COAL MINE DRAINAGE

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ABSTRACT

Seasonal changes in physicochemical parameters of Dikhow River at middle reaches were investigated for a period of two years (2016 and 2017). The objective was to determine the pollution status and suitability of domestic supplies to generate benchmark data for the management of river ecosystem, as this river has a great bearing on the socio- agricultural life. The data indicate that the river is under heavy stress of anthropogenic activities like coal mining waste deposition, industrial effluents etc. The Acid mine drainage is an important environmental concern. The study area was divided into three sampling zones viz. Naginimora, Santak and Simaluguri puja ghat. pH, Dissolved Oxygen(DO), Biochemical Oxygen Demand(BOD), Chemical Oxygen Demand (COD) , Electrical conductivity (EC), Turbidity, Total dissolved solids (TDS), Hardness, Alkalinity, Sulphate, Total suspended solids (TSS) were seem fluctuating specially during the monsoon period. The coal mine pollution seems to modulate the sudden changes in those physicochemical parameters. The study indicates activities from anthropogenic sources along the catchment of the river and the data at sampling stations proves the magnitude of such activities on the quality of the river water.

KEY WORDS : Acid mine drainage, Anthropogenic activity, Coal mining, Socio agricultural life, Pollution.

INTRODUCTION

Water is essential for all existing in the planet however it provides zero calories or organic nutrients. Assam is plentiful in water resources being provided with a network of rivers. Rivers are key sources which provide nourishment to all life. But now a days, rivers are in tremendous threat due to human population blast, rapid industrialization, use of fertilizers in agriculture and all other man-made activities. Water quality management is extremely important for human welfare (Gupta 1991; Madhuri *et al*., 2004). It can be said that no water is pure or clean due to presence of some quantities of gases, minerals and life (Goel, 2006). Water with low dissolved or suspended solids and obnoxious gases in addition to low in biological life can be considered as pure (Joshi *et al*., 2009) and such type of water may be required only for drinking purposes while for other uses like agricultural and industry, the quality of water can be quite flexible. The addition of different types of impurities into the aquatic system is mainly due to weathering of rocks, leaching of soils, dissolution of aerosol particles from atmosphere and from several anthropogenic activities like mining, processing and use of metal based materials (Adeyeye, 1994). The changes in the quantity and quality of river are broadly studied by many researchers (Pratil *et al.*, 1971; Offiong and Edet, 1998; Oladele *et al.,* 2010 etc.). The spatial- temporal variation in the trace components in Patuvent River was studied (Riedel *et al*., 2000). The physicochemical characteristics of Manipur river water system, India were also studied (Singh *et al.,* 2010). The seasonal variation of the water quality among different Ghats of river Ganga

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has been analysed by Khatoon *et al.* (2013). Due to unwanted alterations in the physicochemical and biological properties of air, water and soil, people on our globe are on tremendous threat (Mishra and Dinesh, 1991).

Acid mine drainage (AMD) is considered as a major environmental hazard (Ackil and Koldas, 2006). Many researchers have widely studied the effects of acid coal mine drainage which are associated with deterioration of water quality (Harlihy *et al.*, 1990, Maltby and Booth 1991, Winterbourn and McDiffett 1996, Verb and Vis 2000, Cherry *et al.*, 2001, DeNicola and Stapleton 2002, Freund and Petty 2007). AMD is a completely natural process when sulphide – bearing material is exposed to water and oxygen and the mining process can promote AMD generation easily through increasing the quantity of sulphides exposed (Akcil and Koldas, 2006). The common characteristics of AMD are having low pH and high concentrations of heavy metals and other toxic element which have the power to severely pollute the surface water and ground water as well as soil (Peppas *et al.*, 2000). Various physicochemical parameters of water sample of the river Koel, Shankha and Brahmani are studied and revealed that the level of concentration of the metals decreases due to the dilution in the water to a considerable limit mainly in rainy season (Dey *et al.*, 2005).

The present study is an attempt to characterize the trends in physico-chemical properties of water in Dikhow River, Assam especially at middle reaches in relation to coal mining pollution. Major emphasis has been given to the middle reaches since in the upper zone of the Dikhow river bank there exists a huge area of coal dumping site. The mining operation undoubtly plays a significant role in improving wealth and employment opportunity but simultaneously it leads to excessive environmental degradation. Therefore the assessment of physicochemical properties of Dikhow River seems indispensable.

MATERIALS AND METHOD

The present study covers the middle reaches of Dikhow River, a tributary of the mighty Brahmaputra. It is originated from Sema- Naga area in between latitude 26° 05′N and longitude 94°32′ E East of the Naga Hills. The river moves further north and emerges from the hill near Naginimora. The total length of the Dikhow River is 200km and average width is 115m and total catchment area is 43.72sq.Km. The present study covers approximately 31km of the middle reaches (Fig. 1).

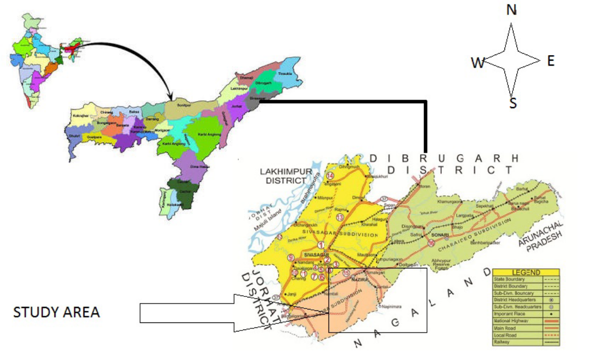

Fig. 1. Map showing the Location of Dikhow River and the study area

In this study, water quality of Dikhow River is reported mainly in the middle reaches from three different zones namely – Naginimora (26° 48′ 33′′ N 94° 48′ 36′′ E) Santak (260 87′ 78′′ N 94° 67′ 78′′ E) and Simaluguri puja ghat (26° 55′ N 94° 46′ E). The data employed were collected during three study periods i.e., Pre monsoon (December to March), Monsoon (April to July) and Post monsoon (August to November).

Water samples were collected in BOD bottles and plastic jerry canes and were brought to the laboratory with necessary precautions for analysis which were done in three replications. For bacteriological analysis, samples were collected in sterilised bacteriological bottles. Three samples were randomly collected from the AMD near the coal dumping sites of Naginimora sampling point which connects the Dikhow River (Fig. 2) and were

Fig. 2. AMD connecting to Dikhow River at Naginimora sampling site

Table1. Mean of different parameters of Acid mine drainage at upper Naginimora zone

Samples	Colour	Temp ^{0}C	pH	SO_2 mg/L	EC µs/cm	TDS ppm	TSS ppm	BOD mg/L	COD mg/L	Cl^- mg/L	Hard mg/L	Ca mg/L	Mg mg/L
1*	Reddish	25	2.1	406	8240	3078	111	7.7	23	53	712	423	289
2**	Reddish	27	2.3	492	10800	5340	124	8.1	30	62	978	587	391
3***	Reddish	26	2.9	342	6790	2238	98	8	21	49	876	534	342
Average		26	2.4	413	8610	3552	111	7.9	24.6	54.6	855	514.6	340.6

Sample1*: upper part of the AMD, sample2*: middle part of the AMD, Sample3***: just before the confluence of AMD and the Dikhow River.

analysed for physico chemical characteristics (Table 1).

The preliminary results of AMD showed that pH was highly acidic, 2.4 as average. The EC and sulphate contents were found also very high. The EC recorded highest as 8610 µmho/ cm and sulphate content was 413 mg/L.

The chemical reaction of formation of AMD as suggested by Johnson and Bradshaw (1979) is summarised:

$$4FeS_2 + 15O_2 + 14H_2O = 4Fe(OH)_3\downarrow + 8H_2SO_4$$

Pyrite+ Oxygen + Water = "Yellow Precipitate"↓ + Sulphuric acid

The standard methods recommended by APHA (1989), CPCB guide manual (2011), Trivedi and Goel (1984) and NEERI (1979) were adopted for determination of various physico-chemical parameters viz. DO, BOD, COD, turbidity, TDS, EC, SS, hardness, Sulphate, phosphate, alkalinity, Ca as $CaCO_3$, Mg as $MgCO_3$, Cl^-, K^+, Na^+. Temperature, pH, Turbidity and Conductivity was measured by using kits (HANNA water analyser HI2168, digital turbidity meter molt-33 (ISO 9001-2008). Statistical analysis was carried through SPSS software.

RESULTS AND DISCUSSION

The findings of the physical and chemical characteristic of water are presented in the Table 2 and 3 respectively.

Normally the water of the river remains clear but it was changed into turbid in the monsoon period. Change of water colour is not harmful due to absence of toxic chemical but the light penetration may get disturbed due to water colour there by inhibiting plant and animal metabolism (Das *et al.*, 2014). Water temperature is the controller of all chemical reactions in an established system and it has direct effects on fish growth, reproduction and immunity (Patil *et al.*, 2012). In accordance to Indian climatic condition maximum recorded water temperature was in monsoon period (23 ^{o}C ± 0.00) in Simaluguri puja ghat station and lowest water temperature (17.38^{0}C ± 0.53) was recorded in Naginimora Station in the pre-monsoon period (Table 2). The change in river water temperature is mainly controlled by season, geographical location, sampling time and the temperature of effluents which connects the stream (Ahipathi and Puttaiah, 2006). It administered a positive correlation with BOD and COD (Table 3) and same results were also recorded from Cauvery river of Kollegal stretch in Karnataka (Venkatesharaju *et al.,* 2010).

In determination of water quality, pH becomes an important factor which can affect other chemical reactions like solubility and metal toxicity (Fakayode, 2005). During the study the pH of the river was more acidic in monsoon period (5.53 ± 0.25, Table 2) and highest pH was recorded in pre monsoon period (7.35 ± 0.07, Table 2) in Naginimora zone. In monsoon period the river comes in contact with the coal mine discharge. The acid coal mine drainage containing high concentration of iron and hydrogen (acid) ions, sulphate and other areas containing waste pyritic materials is a serious threat to the aquatic life (Tuttle *et al.,* 1969). pH is often considered to be the most commonly applied standard that indicates coal mine drainage pollution (Doyle, 1976). The increased values of pH indicate that carbon dioxide, carbonate-bicarbonate equilibrium is influenced more due to change in physico-chemical condition (Karanth, 1987).

DO is one of the important limnological parameter which can indicate the level of water quality and organic pollution in the water body (Wetzel *et al.*, 2006). DO of the river under study was normally higher (7.4 mg/L ± 0.42, Table 2) in the pre monsoon period and lowest (5.55 mg/L ± 0.64, Table 2) in monsoon period at Naginimora zone. Previous study reported that the rivers of Nagaland are rich in DO (7.6 to 9.0 mg/L) (Gurumayum *et al.* 2014). During monsoon the rain water carries the AMD and mix with the river water lowering the DO. In another study in the Jayantia Hills of

Meghalaya the DO was found to be lower in water bodies of the coal mining areas (Swer and Singh, 2003). Sudden lowering of DO could inhibit respiration, induce fish deaths, lower feeding or alter embryonic development and hatching success as a result of oxygen starvation (Clark, 1996). In this study DO administered positive correlation with pH (+0.88) and Hardness (+ 0.92) and negative correlation with EC (-0.94), Sulphate (-0.94) and TDS (-0.86, Table 3). Similar results were recorded from Cauvery river water, Karnataka (Venkatesharaju *et al.,* 2010).

The maximum BOD value (2.38 mg/L± 0.18) was recorded during monsoon period at Santak zone and minimum value (0.86 mg/L ± 0.2) during pre-monsoon period at Simaluguri puja ghat zone (Table 2). The pollutants are mainly organic matter in river water hence can cause an increase in BOD (Kulkarni, 1997). In this study, the river receives organic debris from domestic wastes from the nearby population in the bank of the river. BOD shows positive correlation with Hardness (+0.76) and turbidity (+0.49) (Table 3). Similar findings have also been recorded from Kosi River, Uttarakhand (Bhandari and Nayal, 2008).

The lowest COD value (2.49 mg/L ±0.87, Table 2) was recorded during pre-monsoon period from Simaluguri puja ghat zone and highest (5.43mg/L ±1.24, Table 2) respectively from the same site during monsoon. Seasonal monsoon rain washed the AMD and coal particles, which are discharged and gets mixed with the river water. The coal particles present in coal washeries effluent have direct effect in increasing the value of COD, TDS and TSS of river water (Tiwari and Dhar, 1994). The increased level of COD, TDS and faecal coliform can severely alter the quality of water, making it unsuitable for drinking and also for any other uses (Hari *et al.,* 1994).

Highest turbidity value (34NTU ±4.24, Table 2) was recorded in Simaluguri puja ghat zone in monsoon period and minimum 12.63NTU ±7.60 (Table 2) in Naginimora zone during pre-monsoon period. The Naginimora area is mostly hilly and during monsoon period the rain water carries the soils from the bank and also re suspends the river bed resulting in increased value of turbidity. The intensity and quantity of rainfall mainly affect the erosion thereby enhance the turbidity of nearby drainage (Dooge, 1973).

TDS value was maximum (140 ppm ±3.15, Table 2) during monsoon at Santak point and lowest value (64.25ppm ± 14.5, Table 2) was recorded during post monsoon in the Simaluguri puja ghat point. The present finding is similar to that of Agrawal *et al.* (2009) who recorded maximum value of TDS in monsoon and minimum during the low temperature period. Changes in pH also affect the solubility of the suspended matter (Das *et al.,* 2012). TDS is negatively correlated with pH (-0.52) and positively correlated with EC (+ 0.98) and sulphate (+0.62) (Table 3). In a study it was found that certain coal seams which are associated with pyrite, enters local water body has high value of TDS in association with low pH value (Akcil and Koldas, 2006).

The TSS values varied from 54.63 mg/L ± 21.74 to 125mg/L ± 12.73 (Table 2). The maximum value was recorded in Santak sampling zone in monsoon period and minimum value was recorded in pre monsoon period at Simaluguri puja ghat sampling point. TSS shows a positive correlation with TDS (+0.64) and negative correlation with sulphate (-0.21) (Table 3). Similar findings were recorded in the study of Kosi River (Bhandari and Nayal, 2008).

The most influential water quality guidance on crop productivity is the water salinity hazard as measured by electrical conductivity (Ahmed et al. 2002). EC of water is normally affected by the suspended impurities and also depends upon by the ions present in the water (Agrawal *et al.,* 2009).

The highest EC value (215.63µmho/cm ± 24.93, Table 2) was recorded in Naginimora during the monsoon period and lowest (106.13 µmho/cm ± 36.59, Table 2) during pre-monsoon period in Simaluguri puja ghat.It was probably due to monsoon season, when pH decreases due to addition of acid mine drainage through rain water which in turn increases the impurities in the river water and finally increases the EC. The combination of EC and sulphate analysis can serve as an excellent detection index for coal mining effect (Rikard and Kunkle, 1990). Concentrations of electrical conductivity were found negatively correlated with pH (-0.67) and DO (-0.94) positively correlated with TDS (+0.98) in monsoon period (Table 3). Acid Mine Drainage have low pH, high specific conductivity, high concentrations of iron, aluminium and manganese and low concentrations of toxic heavy metals (Swer and Sing, 2003; Fakayode, 2003). Water with EC less than 250 µmho/ cm is considered as good and that with greater than 750 µmho/ cm is inapplicable for irrigation (Joshi *et al.*, 2009). The quality of

Table 2. Mean and Standard Deviation of different parameters at different sampling stations of Dikhow River of the years 2016 and 2017

Study period		Post monsoon			Monsoon			Pre monsoon		
Parameters	Units	Naginimora Mean ±SD	Santak Mean ±SD	Simaluguri puja ghat Mean ±SD	Naginimora Mean ±SD	Santak Mean ±SD	Simaluguri puja ghat Mean ±SD	Naginimora Mean ±SD	Santak Mean ±SD	Simaluguri puja ghat Mean ±SD
Temperature	^0C	19.88±0.88	22.38 ±0.18	23.00 ±0.00	20.00 ±0.00	21.88 ±1.59	22.63±0.53	17.38±0.53	18.50 ±0.71	18.63 ±0.88
pH		6.50 ±0.10	6.89 ±0.22	7.25 ± 0.18	5.53±0.25	5.94 ±0.08	5.97 ±0.09	7.35 ±0.07	7.31 ±0.44	7.16 ±0.37
DO	mg/L	6.67 ±0.37	6.73 ±0.28	6.88 ±0.32	5.55±0.64	5.99 ±0.22	6.32 ±0.45	7.40 ±0.42	7.14 ±0.33	7.34 ±0.05
BOD	mg/L	1.37 ±0.12	1.43 ±0.18	1.66 ±0.16	1.80 ±0.57	2.38±0.18	2.07 ±0.76	1.01 ±0.01	1.06 ±0.20	0.86 ±0.20
COD	mg/L	3.84 ±0.02	4.00 ±0.14	3.74 ±0.30	3.70 ±0.00	5.36 ±0.34	5.43 ±1.24	3.33 ±0.39	3.54 ±0.93	2.49 ±0.87
Turbidity	NTU	18.25 ±6.36	22.50 ±1.41	23.38 ±1.94	31.63 ±2.30	32.88 ±4.07	34.00 ±4.24	12.63 ±7.60	14.50 ±3.54	17.00 ±0.00
TDS	ppm	69.25 ±22.63	69.25 ±12.73	66.63 ±7.25	138.25 ±4.60	140.23 ±3.15	99.50 ±64.35	77.75 ±13.08	80.50 ±10.61	64.25 ±14.50
TSS	ppm	80.25 ±58.34	78.25 ±41.01	77.63 ±48.97	121.63 ±5.13	125.00±12.73	121.11 ±14.29	73.13 ±11.14	68.63 ±30.25	54.63 ±21.74
EC	µs/cm	137.50±10.25	145.13±10.08	127.25 ±28.28	215.63±24.93	208.13±25.28	166.75 ±1.06	106.75±25.81	116.38±40.48	106.13 ±36.59
Sulphate	mg/L	83.25 ±27.22	74.00 ±4.95	66.50 ±3.18	187.00±67.18	132.50±28.99	118.63 ±37.65	55.88 ±24.22	47.13 ±19.62	38.25 ±2.47
Alkalinity	mg/L	41.38 ±10.08	43.25 ±13.08	42.63 ±11.14	42.25 ±3.89	40.63 ±4.77	43.38 ±3.71	46.00 ±3.54	60.00 ±22.63	52.50 ±37.48
Hardness	mg/L	56.63 ±27.05	39.25 ±1.77	49.88 ±12.55	50.63±3.71	65.38 ±21.74	68.00 ±26.87	40.63 ±4.42	41.13 ±5.83	47.50 ±9.19
Ca as $CaCO_3$	mg/L	37.50 ±18.38	24.25 ±1.06	30.50 ±7.42	33.25 ±1.77	43.13 ±15.73	45.88 ±22.45	25.13 ±0.88	26.00 ±4.24	30.75 ±3.89
Mg as $MgcO_3$	mg/L	14.58 ±2.23	15.00 ±0.71	19.13 ±4.77	18.88 ±0.18	22.25 ±6.01	22.13 ±4.42	15.5 ±3.54	15.00 ±1.41	17.25 ±4.60
Na^+	mg/L	2.83 ±0.74	2.93 ±1.59	2.71 ±0.62	3.63 ±1.88	2.25 ±0.64	2.70 ±1.13	2.56 ±0.37	2.89 ±0.55	2.80 ±0.42
K^+	mg/L	1.02 ±0.33	0.97 ±0.16	1.15 ±0.32	1.79 ±0.13	1.30 ±0.00	1.52 ±0.02	1.10 ±0.21	1.13 ±0.11	1.29 ±0.16
Cl^-	mg/L	13.25 ±2.83	12.38 ±3.36	14.25 ±2.12	23.75 ±2.47	17.50 ±3.54	18.38 ±7.60	10.63 ±0.88	11.63 ±0.53	14.13 ±0.18

underground water can be ensured effectively by controlling conductivity of water and this may be applied to water quality management of other study area (Kumar *et al.,* 2010). The suspended impurities added to the river water through AMD may be the cause of change in EC of the present water body under study.

The highest value of sulphate (187 mg/ L ± 67.18, Table 2) was recorded in Naginimora station during monsoon period as the acid mine drainage mixed with the river water. The mine drainage water emanating from various collieries were highly acidic in character and contain high values of hardness, sulphate, TDS and iron coupled with low pH values which further resulted in contamination of trace (heavy) metals at significant level (Singh, 1987). The lowest value of sulphate (38.5 ± 2.47 mg/L, Table 2) was recorded during pre-monsoon period in Simaluguri puja ghat zone. The sulphate concentrations were negatively correlated with pH (-0.99), DO (-0.94) and positively correlated with electrical conductivity (+ 0.76) and TDS (+0.62) in monsoon period (Table 3). Sulphate concentration is negatively correlated with pH and positively correlated with conductivity (Harlihy and Mills, 1985). In their study in water of mining areas, the high concentration of sulphate was mainly due to presence of iron sulphide in coal and rocks and its reaction with water and oxygen (Swer and Singh, 2003).

The maximum value of total alkalinity (60.00mg/L ± 22.63, Table 2) was recorded in pre monsoon period and minimum (40.63mg/L ± 4.77, Table 2) was recorded during monsoon period in the same Santak sampling zone. The Na^+ values enumerated were within the range of 2.25 m g/L ± 0.64 to 3.63mg/L ±1.88 and values of K^+ are found within the range of 0.97mg/L ±0.16 to 1.79 mg/L ±0.13. Alkalinity, Na^+ and K^+ values of this river were within the desirable limits of WHO (1993) standards (Table 4).

The highest hardness value (68± 26.87 mg/L, Table 2) was recorded in monsoon period of Simaluguri puja ghat point and lowest value (39.25 mg/L± 1.77, Table 2) was recorded in post monsoon period in Santak zone. The values are within the highest desirable limit (Table 4) prescribed by WHO (1993). Water with hardness value up to 60mg/L are referred as "soft", those having 120-180 mg/L are referred to as "hard". Dikhow River can be categorised as moderately soft (55-65 mg/L) in the upper reaches of Nagaland hills (Gurumayum *et al.*, 2014).

Calcium as $CaCO_3$ was found within the range of 24.25mg/L ±1.06to 45.88± 22.45mg/L (Table 2). The highest value was recorded in monsoon period of Simaluguri puja ghat point and lowest was recorded in the post monsoon period of Santak point. Mg as $MgCO_3$ was found highest (22.25mg/L ± 6.01, Table 2) at Santak study zone in monsoon period and lowest value (14.58 mg/L ± 2.23, Table 2) was recoded in post monsoon period of Naginimora sampling point. The values of Ca and Mg of the water samples are within the highest desirable or maximum permissible limits set by WHO (1993) showed in the Table 4.

The chloride content was recorded highest 23.75mg/L± 2.47 (Table 2) in monsoon period and lowest 10.63 mg/L± 0.88 (Table 2) in pre-monsoon period of the same at Naginimora sampling zone which are under the standard limits of World Health Organisation (WHO, 1993). The major source of chloride is from weathering of rock and it can be an indicator of polluted water as we can easily detect the quality of the water by testing the chlorine content in the water (Mishra *et al.*, 2009). Chloride contents of the water samples are found within the highest desirable limits of WHO (1993) as shown in the Table 4.

The two years (2016 and 2017) study of Dikhow River is illustrated (Fig. 3). As the fluctuation in physicochemical parameters are found especially in monsoon season, a comparison is also illustrated (Fig 4). The physicochemical parameters of AMD and the Dikhow River are compared and illustrated in Fig 5 (A and B).

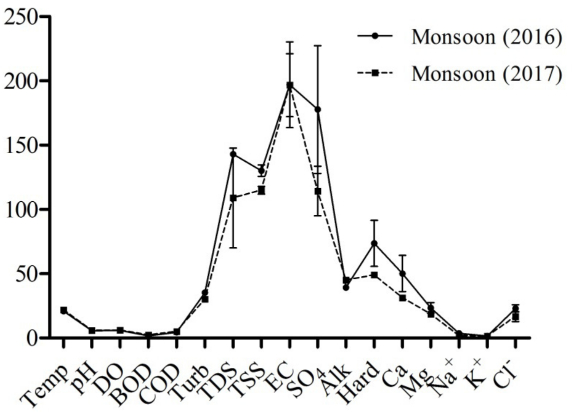

Fig. 3. Comparison of the mean and standard deviation of physicochemical parameters of Dikhow River between 2016 and 2017 during the study

Mining activities results in drainage of sulphide containing waste rock and the most probable sources of acidic drainage is pyrite (FeS_2) which is usually dominant with iron sulphides (Ackil and Koldas, 2006). The important parameters affecting pyrite oxidation are pH, concentration of oxygen, temperature, concentration of Ferric iron and surface area of minerals (Lowson, 1982 and Nordstorm, 1982). The overflowing water from

Table 3. Correlation coefficients between selected physico-chemical parameters of Dikhow River studied for the two years (2016 and 2017)

	Temp	pH	DO	BOD	COD	Turb*2	TDS	TSS	EC	SO_4	Alkal*	Hard*1
Temp	1.00											
pH	0.98	1.00										
DO	0.96	0.88	1.00									
BOD	0.66	0.81	0.44	1.00								
COD	0.97	1.00	0.87	0.83	1.00							
Turb*2	0.98	0.91	1.00	0.49	0.90	1.00						
TDS	-0.69	-0.52	-0.86	0.08	-0.49	-0.83	1.00					
TSS	0.12	0.33	-0.15	0.82	0.36	-0.09	0.64	1.00				
EC	-0.81	-0.67	-0.94	-0.10	-0.65	-0.92	0.98	0.48	1.00			
SO_4	-1.00	-0.99	-0.94	-0.73	-0.99	-0.96	0.62	-0.21	0.76	1.00		
Alkal*	0.18	-0.04	0.43	-0.62	-0.07	0.38	-0.83	-0.96	-0.72	-0.09	1.00	
Hard*1	0.99	1.00	0.92	0.76	0.99	0.94	-0.58	0.26	-0.72	-1.00	0.04	1.00

*Alkalinity, *2Turbidity, *1Hardness

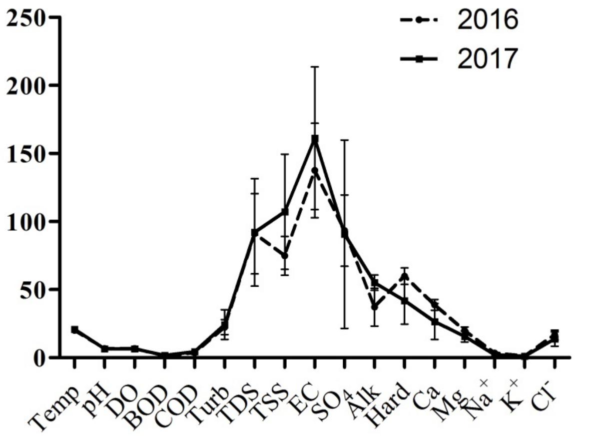

Fig. 4. Comparison between of the mean and standard deviation of physico-chemical parameters between the monsoon seasons of 2016 and 2017 during the study

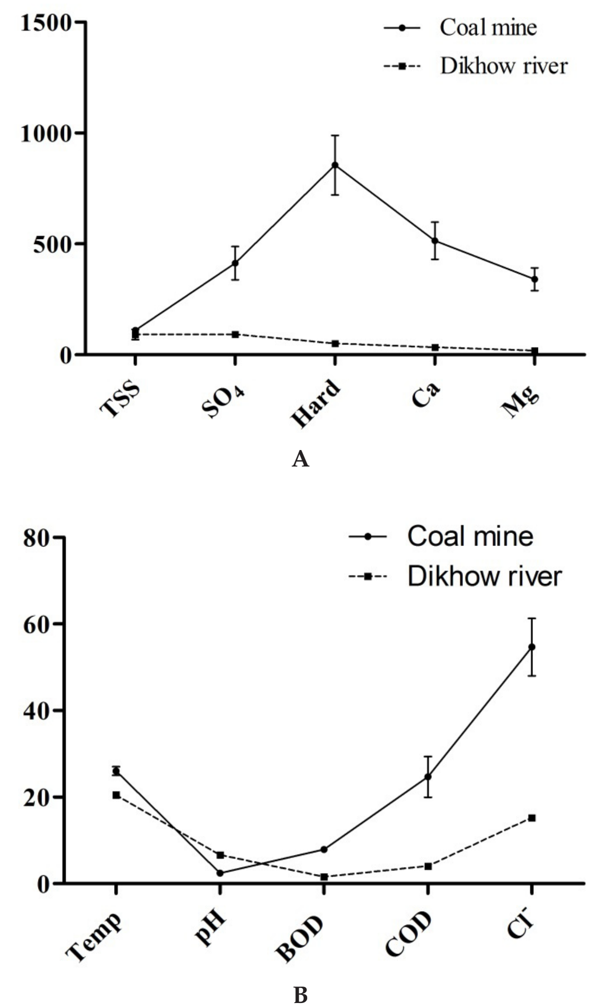

Fig. 5(A, B). Comparison between the physicochemical parameters of AMD and the Dikhow river water.

Table 4. The average values of physico-chemical parameters of Dikhow River water with the WHO limits

Parameters	Who standards HDL	Who standards MPL	Experimental 'values mg/L
pH	7-8.5	6.5-9.5	5.53-7.35
DO	5.0-8.0	-	5.55-7.4
BOD	1.3	-	0.86-2.38
COD	-	-	2.49-5.43
Turbidity	5	-	12.63-34.00*
TDS	500	1000	64.25-140
TSS		-	54.63-125
EC	-	-	106.13-215.63**
Sulphate	200	400	38.23-187
Alkalinity	200	-	40-60
Hardness	100	500	39.25-68.00
Ca as $CaCO_3$	75	200	24.25-45.88
Mg as $MgCO_3$	30	150	14.58-22.25
Na^+	-	200	2.56-3.63
K^+	-	-	0.97-1.79
Cl^-	200	600	10.63-23.75

HDL: Highest desirable limit, MPL: maximum permissible limit, *Turbidity in NTU, **EC in µs/cm

water filled mines and open pits in pyrite and coal mine areas were often acidic and severely polluted by metals and sulphates (Christensen *et al.*, 1996).

CONCLUSION

The present study suggests that the water quality of the Dikhow River is still suitable for drinking purpose during pre-monsoon and post-monsoon periods. In monsoon period the river became the victim of the AMD and as a result some parameters fluctuated. So it is suggested further improvements, precautions and remediations against the acid mine drainage.

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