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Impact of Coal Mining on the Tzuong River System of Mokokchung, Nagaland

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Abstract

The Changki valley area is traditionally regarded as the rice bowl region providing the supply of stable food to a large population of the Ao Naga tribe dwelling in the foothill regions of Nagaland, India. Rampant and unscientific coal mining in and around the Changkikong range has painted a grim future for the area due to severe environmental degradation. Mine tailings and the lack of treatment or mitigation measures have led to the spread of acid mine drainage (AMD) in nature and are the primary source of contaminants for the Tzuong River system. The pollution has also threatened the livelihood of the indigenous people and endangered numerous aquatic species that once thrived in these streams with extinction, some of which are still yet to be identified. Fourteen samples of water are collected at the Tzuong river as well as from its tributaries for physicochemical analyses. Results show that the natural water is significantly compromised and is highly acidic besides high total dissolved solids (TDS), iron and copper concentrations. Assessment of the index of water quality (WQI) by employing the weighted arithmetic indexing (WAI) approach categorizes the stream waters under "unsuitable for drinking purpose" status with WQI scores >100.

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Keywords

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Introduction

Coal mining contributes significantly to a country's economic development, although it greatly impacts human health and the environment. A vast area of farmland, mountains, and forests are cleared to make way for coal mines which is of great concern. The long-term and continuous mining of coal can have serious impact on the natural environment, including contamination of the soil, land subsidence, and deterioration of stream ecosystems.[1-3] Furthermore, the disposal of waste materials from the coal mines interacts with nearby water bodies, which has an irreversible impact on the aquatic and terrestrial environment.[4]

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The mining of coal is often accompanied by the generation of huge quantities of dust and loose materials during the excavation of overburden and the mineral. The severity of the effects of coal mining is mainly influenced by factors such as the area's geology, and composition of overburden and minerals in the coal, mining type, the scale of mining operations, rainfall, etc.[5-9] The waste material mainly in the form of overburden, that is removed before the extraction of coal usually contains many toxic chemicals and pollutants such as heavy metals. This leaches out specially during the rains and pollutes the surrounding area.[10] One major cause of water contamination is the generation of acid from the oxidation of sulphur-bearing minerals like pyrite in coal mines.[11,12] Acid mine drainage (AMD) results due to the reaction of Pyrites with water and air, forming sulphuric acid and some dissolved iron. The resulting contamination from AMDs lowers the pH of the affected water bodies leading to acidity, which in turn facilitates the leaching of toxic metals into the water.[13,14]

Nagaland forms part of the mobile morpho-tectonic unit of the Indian Plate that collided with the Burma Plate.[15] Based on the morpho-tectonic element, Nagaland can be classified into four distinctive units from west to east, i.e., Belt of Schuppen (BoS), Inner Fold Belt (IFB), Naga Hills Ophiolite, and the Naga Metamorphics.[16-18] All of these major structures have NE-SW trends. The study area is a part of the BoS, a zone of imbricate thrusts sheets characterized by discrete litho-tectonic blocks.[19-21] The BoS, bounded by Naga Thrust on the northwest and by the Disang Thrust on the southeast,[22] covers an area of ~4500 sq km and has a length of ~300 km.[23] Sediments in this belt range from Eocene to Oligocene and Plio-Pleistocene, comprising Barail, Surma, Tipam Groups, Namsang, and Dihing formations.

Coals in Nagaland are of sub-bituminous rank deposited under the influence of the marine environment.[24] A similar depositional environment has been revealed in the study of Singh *et al.,* (2012)[25] from the Tiru valley coalfield. Within the BoS, tertiary coal occurs associated with the Tikak Parbat formation of the Barail Group, which is composed of fine to medium-grain sandstone with minor intercalations of shales.

Extensive coal mining in and around the Changkikong range of Mokokchung has irreparably changed the landscape and highly degraded the water bodies. The deterioration in the quality of water and soil because of activities related to coal mining in the Mokokchung region of Nagaland was stressed by workers such as Tiakaba (2016),[26] Semy and Singh (2019, 2021a, 2021b),[27-29] and Semy *et al.,* (2022).[30] The purpose of the study is to determine the ramification of coal mining on the Tzuong River and its tributaries. It involves the analysis of physicochemical properties and evaluation of the Water Quality Index (WQI) of samples collected from Tzuong River and its tributaries. The use of WQI for this study is to assess whether the water quality in the Tzuong River system is affected by coal mining.

Study Area

Area considered for investigation has been taken up from the Changkikong valley of Mokokchung district, Nagaland. It is part of Survey of India (SOI) topographic map No. 83/J7 and lies between the latitude 26°28'18.321" N and 26°24'31.308"N and longitude of 94°24'18.291"E and 94°19'19.254"E, with a coverage of about 21 sq. km (Fig. 1). The preferred method of coal mining is rat-hole mining; however, open cast mining is also becoming quite popular in the recent years (Fig. 2a, b). Coal mining is primarily seasonal, and mining activities are undertaken during the month of October to April before the onset of the Indian Monsoon. The majority of the mining activities are managed and controlled by individual landowners. Coal mining is assumed to be more lucrative, and the appeal of making monetary income quickly has led to a decline in the age-old traditional practice of agriculture and farming as a source of livelihood in the area. The contamination of the irrigation water source from mines and degradation of cultivable land into wasteland areas are also responsible for the weaning away from such agrarian occupation (Fig. 2c). Tzuong river (Fig. 2d) which originates from Mangkolemba town as the Tsujenyong river, flows in the NE-SW direction and eventually drains as 4th order stream into Tsurong river in the neighbouring district of Wokha.

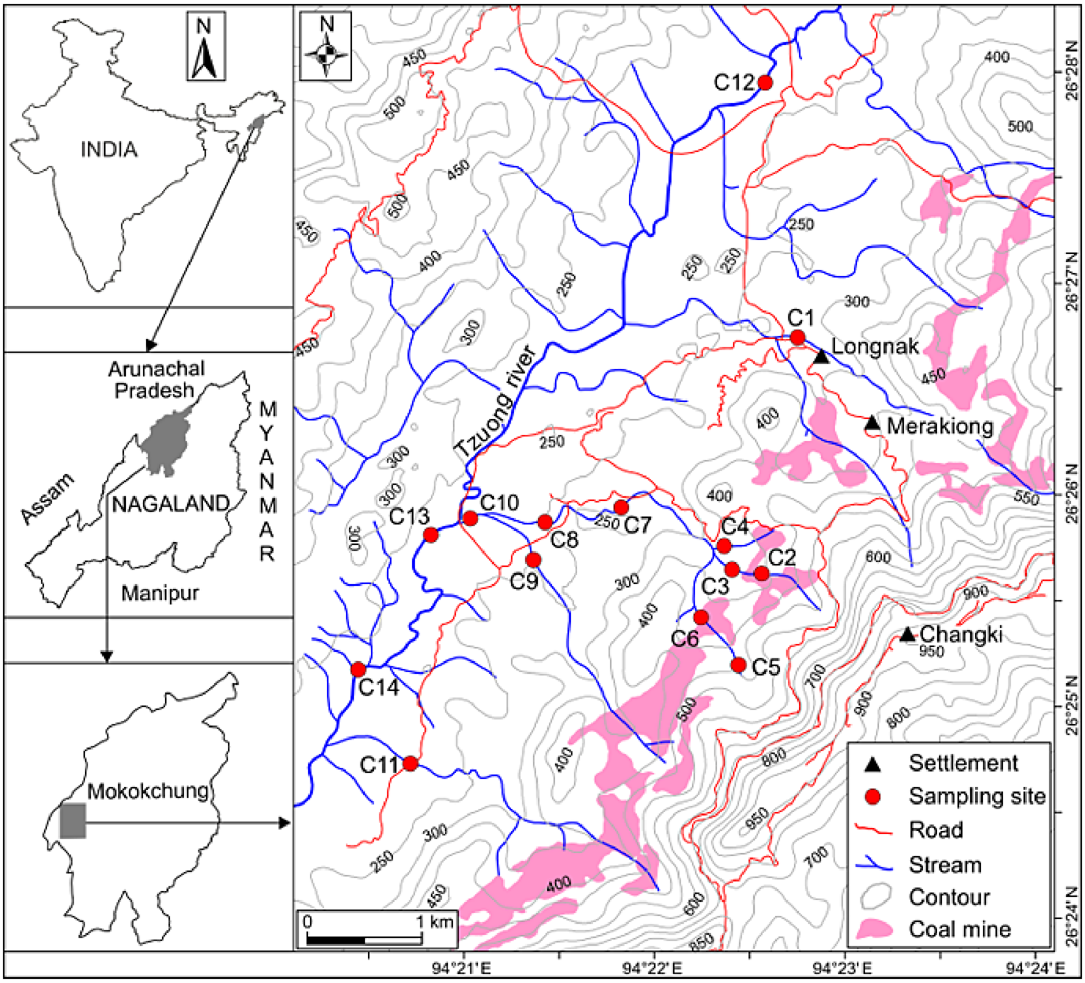

Fig. 1: Location map of the study area with sampling sites

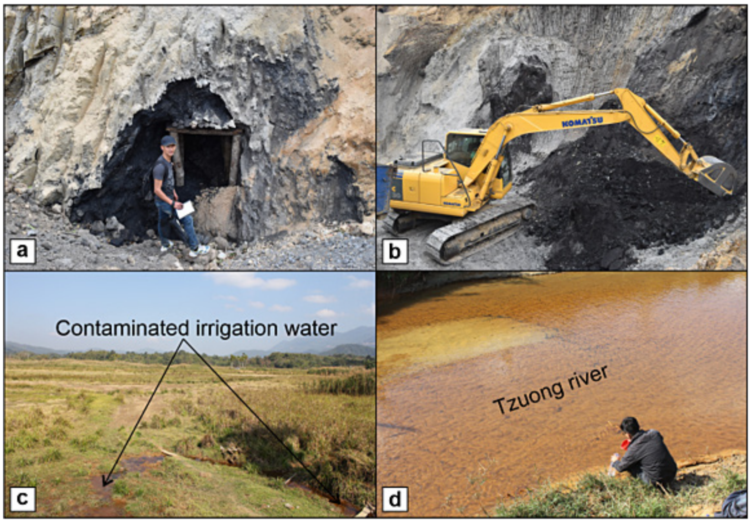

Fig 2: Field photographs a - Rathole mine; b - Open cast mine; c - Abandoned paddy field due to contamination of irrigation water; d – Water sampling at Tzuong river

Methodology

To assess the implications of coal mining on the water regime in the Changkikong valley of Mokokchung, water has been sampled from the Tzuong river and its adjoining tributaries. The tributaries that flow into the Tzuong river mostly are 2nd and 3rd-order streams. The research methodology is given as a flowchart (Fig 3). Altogether 14 water samples were collected to analyze pH (Potential of Hydrogen), Total Dissolved Solids (TDS), nitrate, total hardness, magnesium hardness, calcium hardness, iron, and copper. Samples were collected in 2 L polypropylene bottles, and tagged with a unique identification number and each sampling site marked by GPS (Global Positioning System).

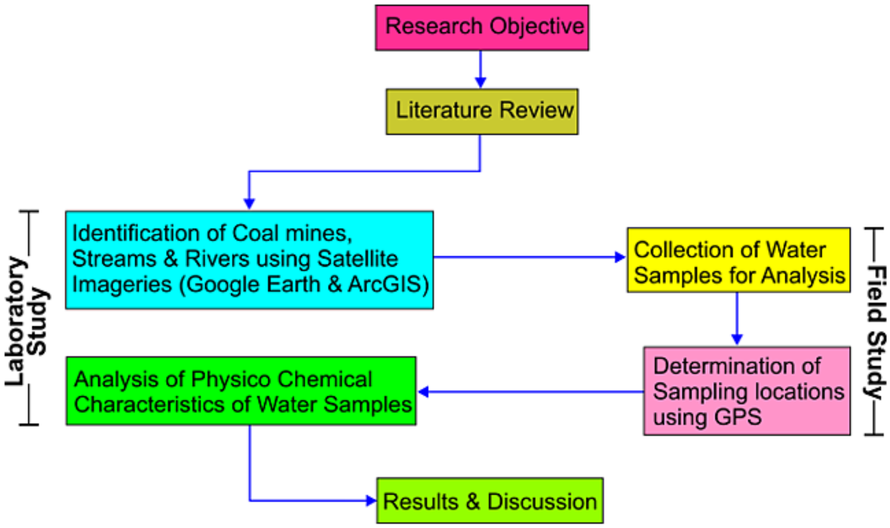

Fig 3: Flowchart of research methodology

Analysis of pH (Potential of Hydrogen) was done with a digital pH meter (EcoTestr pH1, Eutech Instruments) at the sampling site, while research for TDS was done using the gravimetric method according to Bureau of Indian Standards (BIS) 3025 (1984).[31] Total hardness, magnesium hardness, and calcium hardness were analyzed using the titrimetric EDTA (ethylenediamine tetra acetic acid) method according to BIS 3025 (2009, 1991, 1994).[32-34] Nitrate, iron, and copper analysis were done with Spectroquant Pharo 300, Merck KGaA, Germany, using the test kit.

WQI was calculated to estimate the status of water using the physicochemical parameters of the samples. Here, the general quality of the water during a specific location or time is expressed by a single number by incorporating several quality parameters of water. This ensures that the data sourced from various parameters of water is reduced into a value that is logical and simplified.[29,35-37] The method, Weighted Arithmetic Index (WAI)[38] was employed to determine WQI following:

$$WQI= \sum Q_n W_n / \sum W_n$$

Here, Q_n = Quality rating of nth water quality parameter, W_n = Unit weight of the *n*th water. Q_n is determined using equation,

$$Q_n=100 [(V_n-V_i)/(V_s-V_i)]$$

Here, V_n = real amount of the nth parameter present,
Vi = ideal parameter value [V_i = 0, except for pH (V_i = 7)],
V_s = standard permissible value[39] for nth water.
W_n (Unit weight) is derived using the equation,

$$W_n=k/V_s$$

where, k is the proportionality constant and is derived by following

$$k = 1/\sum 1/V_s]$$

where ∑ (1/V_s = 1//V_s (pH) + 1//V_s (TDS) + 1/V_s (total hardness) + 1/V_s (calcium hardness) + 1/V_s (magnesium hardness) + 1/V_s (nitrate) + 1/V_s (iron) + 1//V_s (copper). The BIS standard for drinking water category, as well as weightage accorded to each of the physicochemical parameter, are used for calculating the WQI, as shown in Table 1, while the range of the WQI and its status are shown in Table 2.

Table 1: BIS Standard and the Unit weight of different parameters to determine WQI

Parameter (mg/L)	BIS standard (Vs)	Unit weight (Wn)
pH (0.00-14)	6.5-8.5	0.0050005
TDS	500	0.0000850
Total hardness as $CaCO_3$	200	0.0002125
Calcium Hardness	75	0.0005667
Magnesium Hardness	30	0.0014168
Nitrate	45	0.0009445
Iron	0. 3	0.1416820
Copper	0. 05	0.8500919

Table 2: Water quality index range and status of water sample[40]

WQI range	WQS
0.00-25.00	Excellent
26.00- 50.00	Good
51.00- 75.00	Poor
76.00- 100.00	Very poor
Above 100	Unsuitable for drinking

Table 3: Physicochemical characteristics of the water samples

Sampling site	pH	TDS	Total mg/L	Calcium Hardness	Magnesium Hardness	Nitrate Hardness	Iron	Copper
C1	3	336	68	40	6.83	0.7	3.14	0.02
C2	3.2	276	36	24	2.92	0.8	2.74	0.08
C3	3	429	68	32	8.79	1.6	3.72	0.02
C4	3.5	32.1	88	56	7.81	0.7	1.73	0.03
C5	5.7	38	72	12	14.64	0.6	0.27	0.01
C6	3.3	202	108	20	23.91	0.8	3.17	0.08
C7	2.9	411	52	32	4.89	0.7	2.86	0.02
C8	3	416	80	56	5.86	0.5	4.77	0.03
C9	3.7	119	72	48	5.86	0.8	4.58	0.04
C10	2.7	587	80	52	6.83	0.5	4.22	0.05
C11	2.9	525	152	56	23.42	1.7	4.74	0.04
C12	3.3	166	184	44	34.16	0.6	0.8	0.09
C13	3.1	271	92	44	11.71	0.6	3.39	0.06
C14	3.2	238	96	48	11.71	0.8	1.65	0.05

Results and Discussion

Physicochemical Parameters

Table 3 shows the physicochemical properties of all the samples tested. pH is a very important criterion for evaluating water quality as it affects the behaviour of metals in the environment.[41,42] The pH level of the water samples ranges between 2.7-5.7, which exceeds the limit of permissibility according to the BIS standard (Table 1). The sample collected at sampling site C10 with a pH of 2.7 is the most acidic. TDS, which is the measure of dissolved ionic concentrations, ranged between 32.1-587 mg/L, where 587 mg/L (highest value) was recorded at C10. As per BIS standard, samples collected at sites C10 and C11 exceeded the permissible limit with values of 587 and 525 mg/L, respectively. Contamination from AMD where oxidation of pyrite (FeS_2) into dissolved iron, sulfate, and hydrogen has led to increased acidity and total dissolved solids of the water.[43-45]

The total hardness in all the sampling sites is found to be in the permissible limit of BIS standard and ranges from 36-184 mg/L. The concentration of calcium hardness ranges from 12-56 mg/l. Calcium values of all the water samples are found to be within the BIS permissible limit. Magnesium hardness range from 2.92-34.16 mg/L. The sample collected at site C12 has the highest magnesium value of 34.16 mg/L exceeded the BIS permissible limit, while the rest fell within the permissible limit.

The amount of nitrate in all the samples is found to be low and occurred within BIS permissible limit with values ranging from 0.5-1.7 mg/L. Nitrogen in soil and bedrock is released as nitrate in the presence of air and water during the excavation process and mining.[46] Low nitrate levels in the samples may be attributed to a lower level of nitrogen in the soils and bedrocks of the study area. Similar results were reported by Semy and Singh (2019, 2021a, 2021b).[27-29]

The concentration of iron ranges from 0.27-4.77 mg/L. The sample collected at site C8 has the highest concentration of iron at 4.77 mg/L. All the samples, with the exception of site C5 (0.27 mg/L), have a high iron concentration that exceeds the BIS permissible limit. Concentration of copper in the samples varied between 0.02-0.09 mg/L. The samples at site C2, C6, C12, and C13 with a copper concentration of 0.08, 0.08, 0.09, and 0.06 mg/L respectively, occurs beyond the BIS permissible limit while the remaining samples lie within the permitted limit. Pyrite (FeS_2) and Chalcopyrite ($CuFeS_2$), which are released during coal mining operations, are accountable for the high iron and copper in the samples.[44, 47,48]

Table 4: Calculation of WQI for sites C1, C2, and C3

Parameters	C1			C2			C3		
	V_n	Q_n	W_nQ_n	V_n	Q_n	WnQ_n	V_n	Q_n	W_nQ_n
pH	3	-266.667	-1.33348	3.2	-253.333	-1.2668	3	-266.667	-1.33348
Total dissolved solids	336	67.2	0.005713	276	55.2	0.004693	429	85.8	0.007294
Total Hardness	68	34	0.007226	36	18	0.003825	68	34	0.007226
Calcium Hardness	40	53.33333	0.030225	24	32	0.018135	32	42.66667	0.02418
Magnesium Hardness	6.83	22.76667	0.032256	2.92	9.733333	0.01379	8.79	29.3	0.041513
Nitrate	0.7	1.555556	0.001469	0.8	1.777778	0.001679	1.6	3.555556	0.003358
Iron	3.14	1046.667	148.2938	2.74	913.3333	129.4029	3.72	1240	175.6857
Copper	0.02	40	34.00367	0.08	160	136.0147	0.02	40	34.00367
	ΣW_nQ_n = 181.0409			ΣW_nQ_n = 264.1929			ΣW_nQ_n = 208.4394		
	WQI = 181.04			WQI = 264.19			WQI = 208.44		

Water Quality Index Analysis

The highest W_n value of 0.85 assigned to copper followed by iron at 0.14 (Table 1) suggests their significance in impacting the result of WQI. The observed value for each physicochemical parameter of all the sample areas and their WQI values is shown in Tables 4, 5, 6, 7, and 8. From the WQI scores, iron and copper were found to have the highest influence among all other parameters considered for the study.

Table 5: Calculation of WQI for sites C4, C5, and C6

Parameters	**C4**			**C5**			**C6**		
	V_n	**Q_n**	**W_nQ_n**	**V_n**	**Q_n**	**W_nQ_n**	**V_n**	**Q_n**	**W_nQ_n**
pH	3.5	-233.333	-1.16679	5.7	-86.6667	-0.43338	3.3	-246.667	-1.23347
Total dissolved solids	32.1	6.42	0.000546	38	7.6	0.000646	202	40.4	0.003434
Total Hardness	88	44	0.009351	72	36	0.007651	108	54	0.011476
Calcium Hardness	56	74.66667	0.042316	12	16	0.009068	20	26.66667	0.015113
Magnesium	7.81	26.03333	0.036885	14.64	48.8	0.069141	23.91	79.7	0.112921
Nitrate	0.7	1.555556	0.001469	0.6	1.333333	0.001259	0.8	1.777778	0.001679
Iron	1.73	576.6667	81.70327	0.27	90	12.75138	3.17	1056.667	149.7106
Copper	0.03	60	51.00551	0.01	20	17.00184	0.08	160	136.0147
	ΣW_nQ_n = 131.6326 WQI = 131.63			ΣW_nQ_n = 29.4076 WQI = 29.41			ΣW_nQ_n = 284.6365 WQI = 284.64		

Table 6: Calculation of WQI for sites C7, C8, and C9

Parameters	**C7**			**C8**			**C9**		
	V_n	**Q_n**	**W_nQ_n**	**V_n**	**Q_n**	**W_nQ_n**	**V_n**	**Q_n**	**W_nQ_n**
pH	2.9	-273.333	-1.36681	3	-266.667	-1.33348	3.7	-220	-1.10012
Total dissolved solids	411	82.2	0.006988	416	83.2	0.007073	119	23.8	0.002023
Total Hardness	52	26	0.005526	80	40	0.008501	72	36	0.007651
Calcium Hardness	32	42.66667	0.02418	56	74.66667	0.042316	48	64	0.036271
Magnesium Hardness	4.89	16.3	0.023094	5.86	19.53333	0.027675	5.86	19.53333	0.027675
Nitrate	0.7	1.555556	0.001469	0.5	1.111111	0.001049	0.8	1.777778	0.001679
Iron	2.86	953.3333	135.0702	4.77	1590	225.2743	4.58	1526.667	216.3012
Copper	0.02	40	34.00367	0.03	60	51.00551	0.04	80	68.00735
	ΣW_nQ_n = 167.7683 WQI = 167.77			ΣW_nQ_n = 275.033 WQI = 275.03			ΣW_nQ_n = 283.2817 WQI = 283.28		

Table 7: Calculation of WQI for sites C10, C11, and C12

Parameters	**C10**			**C11**			**C12**		
	V_n	Q_n	W_nQ_n	V_n	Q_n	W_nQ_n	V_n	Q_n	W_nQ_n
pH	2.7	-286.667	-1.43349	2.9	-273.333	-1.36681	3.3	-246.667	-1.23347
Total dissolved solids	587	117.4	0.00998	525	105	0.008926	166	33.2	0.002822
Total Hardness	80	40	0.008501	152	76	0.016152	184	92	0.019552
Calcium Hardness	52	69.33333	0.039293	56	74.66667	0.042316	44	58.66667	0.033248
Magnesium Hardness	6.83	22.76667	0.032256	23.42	78.06667	0.110606	34.16	113.8667	0.161329
Nitrate	0.5	1.111111	0.001049	1.7	3.777778	0.003568	0.6	1.333333	0.001259
Iron	4.22	1406.667	199.2993	4.74	1580	223.8575	0.8	266.6667	37.78186
Copper	0.05	100	85.00919	0.04	80	68.00735	0.09	180	153.0165
	ΣW_nQ_n = 282.9661			ΣW_nQ_n = 290.6796			ΣW_nQ_n = 189.7831		
	WQI = 282.97			WQI = 290.68			WQI = 189.78		

Table 8: Calculation of WQI for sites C13 and C14

Parameters	**C13**			**C14**		
	V_n	Q_n	W_nQ_n	V_n	Q_n	W_nQ_n
pH	3.1	-260	-1.30014	3.2	-253.333	-1.2668
Total dissolved solids	271	54.2	0.004607	238	47.6	0.004046
Total Hardness	92	46	0.009776	96	48	0.010201
Calcium Hardness	44	58.66667	0.033248	48	64	0.036271
Magnesium Hardness	11.71	39.03333	0.055303	11.71	39.03333	0.055303
Nitrate	0.6	1.333333	0.001259	0.8	1.777778	0.001679
Iron	3.39	1130	160.1006	1.65	550	77.92509
Copper	0.06	120	102.011	0.05	100	85.00919
	ΣW_nQ_n = 260.9157			ΣW_nQ_n = 161.775		
	WQI = 260.92			WQI = 161.78		

Table 9 shows the compilation of the WQI values for all the studied samples. The result indicates that the sample from site C5 having a 29.41 WQI value, is good water quality, while the other remaining samples are all categorised as Unsuitable for drinking.

The low WQI value of site C5, is due to the fact that it is located upstream and away from the influence of coal mines (Fig. 1). The sample with the highest WQI value was recorded at sampling site C11 with a score of 290.68. The high WQI value of site C11 can be attributed to the three streams that converge after passing through the coal mines.

It is observed that the sampling site C5 with an initial WQI value of 29.41 on reaching site C6 is seen to have drastically increased to 284.64 (Fig. 4). The abrupt rise in the WQI value can be directly attributed to contamination from surface run-offs from coal mines as the stream at site C6 passes through the mining area. The stream at site C6, before reaching site C7 converges with two streams flowing from sites C2, C3, and C4 with WQI values of 264.19, 208.44, and 131.63 respectively. On reaching site C7, the WQI value is seen to have decreased immensely to 167.77. An increase in the WQI value is observed with the stream flowing downstream from C7(167.77) to C10(282.97) through C8(275.03). As the stream joins the Tzuong river downstream of site C10, the WQI value gradually starts decreasing from site C13(260.92) to site C14(161.78). The decrease in the WQI value can be attributed to the dilution of pollutants due to increased discharge in the river as a result of inflow from the less polluted/unpolluted tributaries.[49]

Table 9: Summary of WQI and WQS

Sampling site	WQI	WQS
C1	181.04	Unsuitable for drinking purpose
C2	264.19	Unsuitable for drinking purpose
C3	208.44	Unsuitable for drinking purpose
C4	131.63	Unsuitable for drinking purpose
C5	29.41	Good water quality
C6	284.64	Unsuitable for drinking purpose
C7	167.77	Unsuitable for drinking purpose
C8	275.03	Unsuitable for drinking purpose
C9	283.28	Unsuitable for drinking purpose
C10	282.97	Unsuitable for drinking purpose
C11	290.68	Unsuitable for drinking purpose
C12	189.78	Unsuitable for drinking purpose
C13	260.92	Unsuitable for drinking purpose
C14	161.78	Unsuitable for drinking purpose

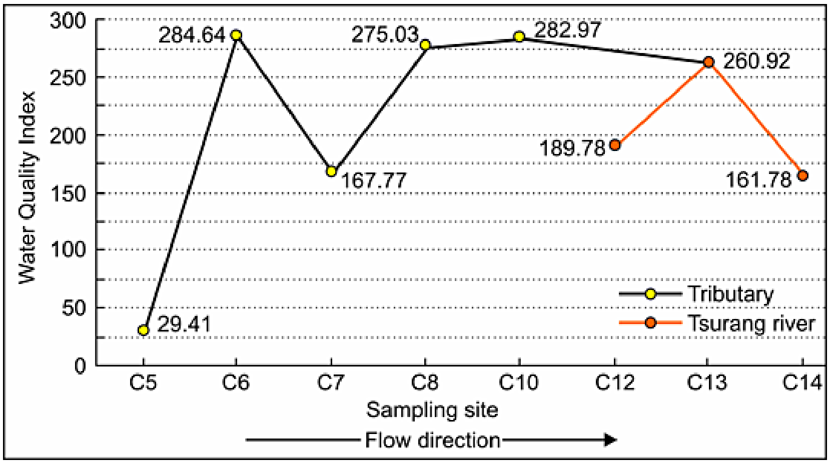

Fig. 4: WQI rating of Tzuong river and its tributaries flowing through sites C5, C6, C7, C8 and C10

The upstream part of the Tzuong river (C12) with an initial high WQI value of 189.78 indicates contamination from coal mines. On reaching C13, the WQI value sharply increases to 260.92. The abrupt increase in WQI value is attributed to contamination from coal mines through its tributaries from sites C1, C2, C4, C6, and C9 (Fig. 1). From site C13(260.92) to C14(161.78) the WQI value sharply decreases which indicates dilution from unpolluted tributaries.

Conclusion

The majority of the water source in the area of study has been highly contaminated by mining activities. Effluents from coal mines in the form of AMD have greatly deteriorated the quality of water of the Tzuong river through its tributaries as evidenced by high acidity, high TDS, iron, and copper concentrations. The overall quality status of the Tzuong river and associated tributaries from WQI values indicate the water to be unsuitable for drinking with iron and copper as the dominant parameters of influence in the WQI scores. Although the pollution levels are still high with high WQI values, the water quality along the Tzuong river is observed to be gradually improving downstream due to the dilution of pollutants by inflow from unpolluted tributaries.

As the entire operation of coal mining is carried out haphazardly by the landowners/locals, with no governmental control or EIA/environmental considerations/legislations in place, there is a strong need for the creation of awareness so that proper environmental protection procedures are followed before any mining activities are initiated as well as to encourage the stakeholders to come forward and volunteer for restoration activities and where possible, minimize and reduce the negative impacts associated with coal mining and its associated activities.

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Conflict of Interest

The authors declare no conflict of interest.

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