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Impact of underground coal mining on surface water and ground water quality

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Abstract

Groundwater contamination and depletion resulting from underground coal mining activities is a worldwide environmental problem. The pumping of groundwater from flooded columns during underground coal mining deteriorates the quality of water and also depletes it. Heavy metals occurring in the earth's crust naturally can interact with water. Direct interaction of water with naturally occurring heavy metals in earth's crust or coal can contaminate water. Groundwater and surface water samples around coal mine area, located at Kallar Kahar, Pakistan were analyzed for Zinc, Cadmium, Lead, Iron, Manganese, Chromium, Nickel, Mercury and Copper concentrations. The analysis showed that the concentration of Iron as compared to other heavy metals was higher. The concentration of Cadmium and Copper was also noticeably high. Copper concentration in water samples ranged from 4.7ppm to 7.8ppm while the concentration of cadmium ranged from 0ppm to 10ppm. All samples contained lead ranging from 0.006ppm to 0.027ppm. Whereas Chromium and Zinc was below detectable limit. No trace of manganese was found in any of the groundwater and surface water samples collected from the mines and the pond. Monitoring wells should be established in the surrounding area to check the contamination of groundwater and instead of coal cleaner fuels should be considered to reduce the need for coal mining.

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Introduction

Water is an important constituent of all the animal and plant life. Increasing population, accelerating industrialization as well as intensification of agriculture and urbanization exert substantial pressure on vast but yet finite water resource. The most common and prominent increasing source of water pollution is industries and mining activities (Reza and Singh, 2010).

The effluents released from there have significant influence on the pollution of water bodies; being capable of completely changing the physical, chemical and biological nature of the receiving water body (Sangodoyin, 1991). The high volume leachate generated from mine waste dumps has the potential to contaminate the surrounding water sources and soil (Alligui and Boutaleb, 2010). However, the most serious problem is groundwater contamination (Firtzgerald, 2000).

Abandoned mines contain significant amount of heavy metals and total dissolved solid (TDS) in their water. These waters may become acidic with the passage of time and are able to solubilize metals contained in the mine and mined materials thus lending high concentrations of metals in solution. The acidic metal containing water may also have the potential to contaminate down gradient groundwater and surface water resources (Groudev, 2008; Saria *et al.,* 2006).

Pakistan has seventh largest coal reserves in the world with approximately 185.5 billion tons of coal. There are large deposits of coal in all four provinces of Pakistan as well as in Azad Jammu and Kashmir. Sindh province has the largest reserve of coal in Pakistan which is approximately 184,623 million tons. Balochistan has 217 million tons, Punjab has 235 million tons and, Khyber Pakhtunkhwa has 91 million tons while Azad Jammu and Kashmir has 9 million tons of coal (Pakistan Coal Power Generation Potential, 2004).

In Punjab, the most densely populated province of Pakistan (490per sq km), major coal reserves (90%) are present at Kallar Kahar area. Here underground coal mining is being practiced.

The area had roughly 150+ mines out of which a subset of five mines was picked up in the study area. Salt Range and Makarwal are the two main coal fields in Punjab. The study area for this research is a cluster of mines owned by the Government of Pakistan and some private companies. This cluster is located on Khushab road in the Kallar Kahar District of Punjab. The coal mines which make up this cluster are Mines of PUNJMIN (Punjab Mineral Development Corporation), KD Well Mines, Geo minerals Mines, SA Latif & Company and Habibullah Mines.

This study is only concerned with those mines which are located in the Salt Range. Around 260 sq.km area is covered by the Salt Range Coal Fields. This 260 sq.km long belt lies between Khushab and Jhelum Districts of Punjab. This coal reserve contains 213 million tons but only 30 million is mineable. Although there are two coal seams present in this area but only one is mineable. The thickness of this coal seam varies but on average it is 0.75m thick. The coal found in this area is Sub bituminous (Pakistan Coal Power Generation Potential, 2004).

Materials and methods

Statement of Human and Animal Rights

This research does not violate any human or animal right.

The selected area is off the main communication artery thus a suitable approach for it is to exit M2 motorway at Kallar Kahar service area, go around the lake and take a south westerly road named Kallar Kahar Khushab road, travel on the same towards Munrah. About 3 kilometers short of Munarah there is a police barrier called Noori Pehra, from here a dirt road branches off on the left and after travelling for 3 kilometers one arrives in the study area as given in Fig. 1.

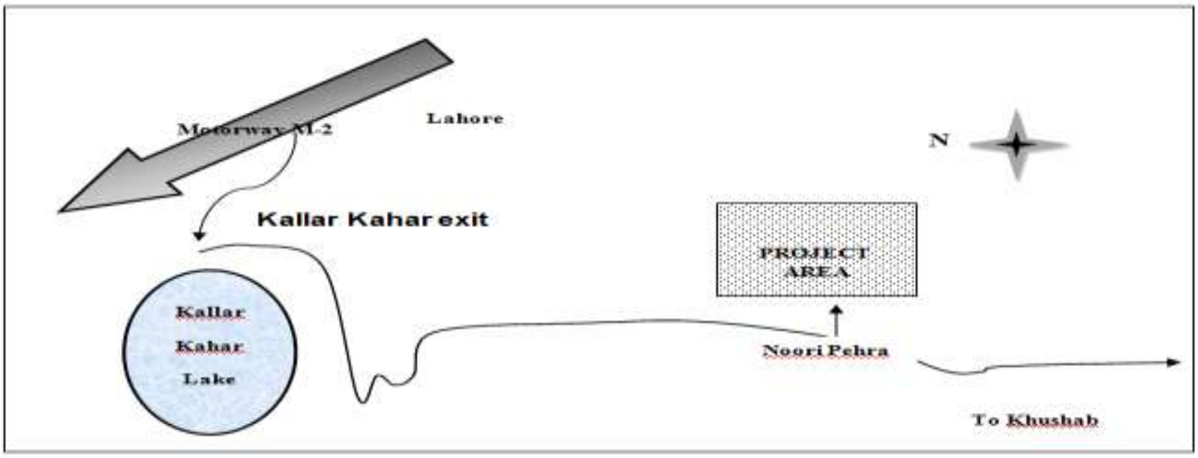

Fig. 1. The route to the study area.

The number of workers at each mine is approximately 100 and the coal contaminated water which is pumped during the mining process is mixed with water pumped through tube well. This water is then used by the mine workers for bathing, washing and animal consumption. Fig. 2 shows the type of sub soil sediments in Kallar Kahar Area.

Samples of ground and surface water were collected and analyzed using standard procedures. Total nine samples were collected from the study area. Out of these nine samples eight were collected from mines and one from a surface pond. One sample of groundwater and one sample of surface water are shared between two of the five mines which were SA Latif and Habibullah Mine as both the mines are in close proximity. The samples were collected using pre-labeled bottles and critical parameters were tested onsite.

Materials used while
Sampling
Clean and labeled bottles of 1.5 litre, Gloves.

Analysis
Beakers, Volumetric Flasks China Dishes, Stirrers Funnels, Tripod Stands, Filter paper, Burner, Weighing machine, Distilled Water, Dissolved Oxygen Meter, pH Meter, Spectrometer, BOD bottles, Incubator, Mac Conkey agar, Petri dishes, Parafilm, Round bottom flask, Nitric acid, Magnetic stirrer, Hot plate, Hydrogen peroxide, Metal containing salts, Atomic absorption spectrometer.

The parameters analyzed included Dissolved Oxygen (DO), Temperature, pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Conductivity, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Coli form Analysis, Copper (Cu), Nickel (Ni), Iron (Fe), Cadmium (Cd), Chromium (Cr), Zinc (Zn), Manganese (Mn), Lead (Pb), Mercury(Hg). Heavy metals were tested by using Atomic Absorption Spectrometer.

The results were then analyzed by comparing them with National Standards for Drinking Water Quality, World Health Organization (WHO) Standards and World Wildlife Fund (WWF) Standards for Recreational Waters for Pakistan.

Results and discussion

Underground coal mining is one of the two methods of coal mining in which burrows are dug deep into the ground. These burrows can intersect with the groundwater reservoir and pollute it. It also leads to the depletion of groundwater which is removed from the flooded columns. This type of groundwater depletion has been observed in a previously conducted research near Damodar river area which showed that coalfields surrounding this area have reduced the groundwater level. (Tiwary and Dhar, 1994).

Table 1. Location and Coordinates of sampling points.

1.	SA Latif & Habibullah Mines	Coordinates
	• Groundwater • Surface Water	32*38.548N, 72* 34.156E
2.	PUNJMIN Mines	
	• Groundwater • Surface Water	32*37.75N, 72*30.948E
3.	Geomineral Mines	32*37.322N, 72*30.812E
	• Groundwater • Surface Water	
4.	KD Wells Mines	32*37.251N, 72*31.733E
	• Groundwater • Surface Water	
5.	Chaab Pond	32*37.33N, 72* 31.521E

Table 2. Standard Methods for analysis of selected parameters.

Sr.no.	Parameters	US EPA method number
1	pH	ASTM D1293-12
2	COD	ASTM D1252- 06
3	BOD	ASTM D6238- 98(2011)
4	TDS	ASTM D5907- 13
5	TSS	ASTM D5907- 13
6	Electrical Conductivity	ASTM D1125- 95(2009)
7	Heavy Metals	ASTM A7000

In the study area the burrows intersect groundwater reservoir at about 350 ft and then reach the coal seam at approximately 450 ft. The selected area included five mines and a pond located in Kallar Kahar near the Salt Range. The coal found in Salt Range has moisture content ranging from 3.2% to 10.8%. The Volatile Matter varies from 21.5% to 38.8%. Whereas fixed carbon and ash content ranges from 25.7% to 44.8% and 12.3% to 44.2% respectively. Sulphur content present in this coal ranged between 2.6% to 10.7%. The heating value of coal lies between 10,131-14,164 BTU/lb (Malkani, 2012).

The groundwater which is pumped out during mining is invariably mixed with the water of tube well or hand pump and this water constitutes the surface water which then runs in the *kutcha* channels for approximately 200 yards and finally evaporates or goes back into the ground. During Monsoon however this water travels more distance and form seasonal ponds out of which Chaab pond is the largest in the study area. The water from these seasonal ponds ends up in a bigger *Nullah* named Neela Wahn. Chaab pond is used by the local people and miners for recreational purposes like swimming and water for their livestock. The volume of water pumped out is approximately 4320 gallons per day and as the mines are operational throughout the year so large amount of water is being depleted from the groundwater reservoir.

Predominant use of water is for animal consumption like goats/cows which are kept by the miners and for washing/bathing. It was found out that stomach and skin diseases are most common among the miners with rare case of tuberculosis.

Table 3. Results of the physical parameters of water samples.

Locations	DO (mg/l)	Temp. (°C)	pH	EC (ms/cm)	TSS (ppm)	TDS (ppm)	FC (CFU)
SA Latif & Habibullah Mines							
Ground Water	1.02	28.0	7.24	21.68	10750	260	Fecal=UL Coliform=2
Surface Water	1.14	33.9	8.13	25.03	16060	300	Fecal=UL Coliform=0
PUNJMIN Mine							
Ground Water	1.17	27.6	7.15	35.04	14110	420	Fecal=476 Coliform=0
Surface Water	0.99	29.4	7.85	8.34	440	100	Fecal=UL Coliform=7
Geo-mineral Mine							
Ground Water	1.29	28.6	8.45	293.67	18510	3520	Fecal=UL Coliform=0
Surface Water	1.17	27.8	7.95	6.67	15860	80	Fecal=UL Coliform=53
KD Wells Mine							
Ground Water	0.71	29.2	6.84	463.86	13700	5560	Fecal=UL Coliform=32
Surface Water	1.27	27.9	8.38	28.365	12550	340	Fecal=UL Coliform=0
Chaab Pond	1.29	32.4	7.71	1461.67	10490	17520	Fecal=UL Coliform=6
NSDWQ			6.5-8.5			<1000	
WHO			6.5-8.5			<1000	
WWF Standards for Recreational Water	4	*	6.5-8.5	1.50		1000	Total= 1000

*The maximum water temperature change shall not exceed 3°C relative to an upstream control point.

Table 4. Heavy Metal Concentration in the water samples of the study area.

Locations	Cd ppm	Cr ppm	Cu ppm	Fe ppm	Ni ppm	Zn ppm	Pb ppm	Hg ppm	Mn ppm
S.A Latif & Habibullah Mines									
• Ground Water	0	BDL	6.6	9.3	2.75	BDL	0.016	BDL	BDL
• Surface Water	10	BDL	5.1	10.7	3.4	BDL	0.012	0.001	BDL
PUNJMIN Mine									
• Ground Water	2.75	BDL	5.8	7.2	1	BDL	0.006	BDL	BDL
• Surface Water	0.5	BDL	5.2	6.76	1	BDL	0.023	BDL	BDL
Geo-mineral Mine									
• Ground Water	0	BDL	7.8	36	30	BDL	0.008	BDL	BDL
• Surface Water	0	BDL	4.7	8.1	1	BDL	0.013	BDL	BDL
KD Wells Mine									
• Ground Water	3.01	BDL	5.2	5.5	1	BDL	0.011	0.001	BDL
• Surface Water	0.5	BDL	5.4	7.69	1	BDL	0.027	BDL	BDL
Chaab Pond	0.5	BDL	7.5	5.3	2.9	BDL	0.007	BDL	BDL
NSDWQ	0.01	≤0.05	2		≤0.02	5.0	≤0.05	≤0.001	≤0.5
WHO	0.003	0.05	2		0.02	3	0.01	0.001	0.5
WWF Standards for Recreational Water	0.01	0.05	1.5			15	0.01	0.001	

Table 3 shows groundwater and surface water quality of the collected samples from the study area. As shown in the above table, pH showed neutral to slightly alkaline nature and was under compliance with both standards given by the Government of Pakistan and World Health Organization (WHO). The results of pH clearly showed that there is no issue regarding acid mine drainage in the study area. Another research conducted in Barapukuria coal mining area in Dinajpur also showed that the pH of the samples was suitable for all purposes (Howladar, 2012). TDS in most samples were also meeting the National Standards for Drinking Water Quality (NSDWQ) and World Health Organization standards except for Geomineral mine groundwater; K.D. Wells mine groundwater and Chaab pond. Higher level of TDS found in the samples can result in reduction of aesthetic value of water by giving it a salty bitter or bad taste. High level of TDS in chaab pond can contribute towards eutrophication which can have harmful effects on the pond's ecology. The water of chaab pond is also used for recreational purposes. When compared with WWF prescribed standards for recreational waters, the concentration of TDS exceeded and showed non compliance with standard.

Total Coliform in water samples was also very high; in fact in case of majority of samples it was unlimited. This high concentration means that the water samples contain large amount of pathogenic bacteria in them which can result in number of diseases and outbreaks. Population uses this water for recreational and drinking purposes and suffers from skin rash, stomach problems, and ear and eye infections. It also has the potential to cause hepatitis.

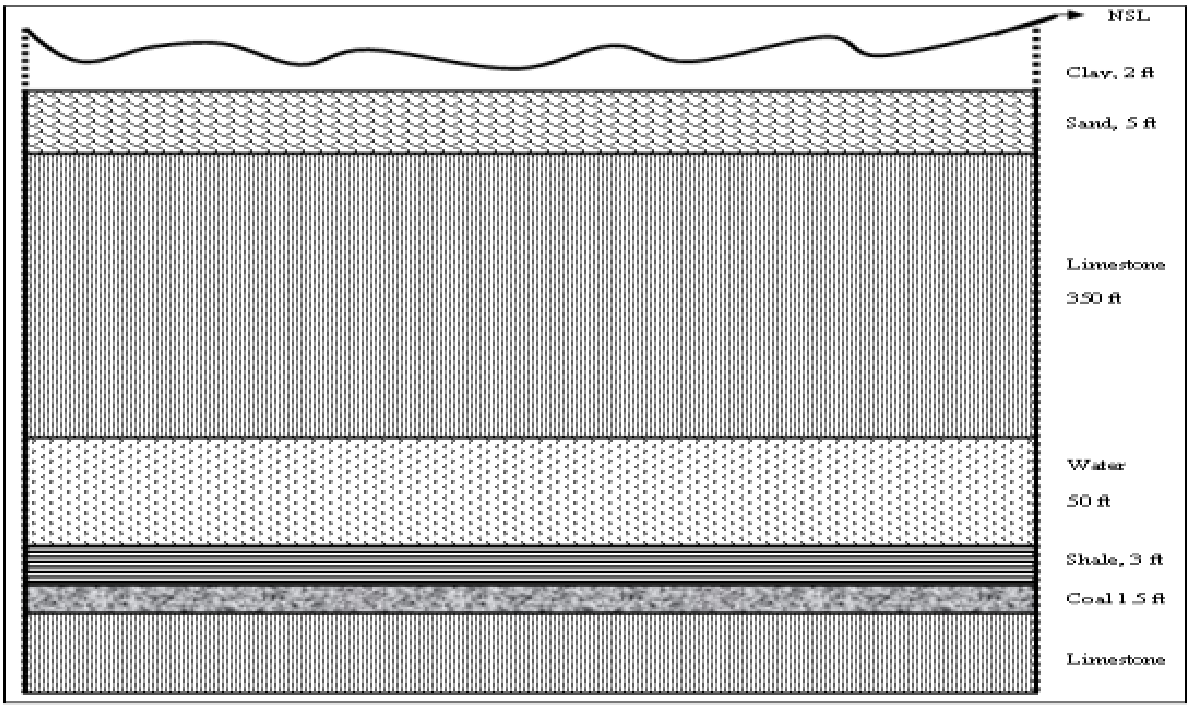

Fig. 2. Sub Soil Strata in Kallar Kahar.

Table 4 shows the concentration of selected heavy metals which was determined using Atomic Absorption Spectrometer. The results showed varying levels of different metals in surface water and ground water samples. Cadmium was present in high amount in the samples except those for Geomineral mines and S.A Latif /Habibullah mines. Cadmium is considered among the most toxic metals and has the potential to cause cancer which means that it is carcinogenic. Consuming large amount of cadmium can damage lungs and can irritate the stomach. This metal can accumulate in human body and cause kidney failures as well as damage the bone structure.

The highest concentration of copper i-e 7.8ppm was found in geomineral mine's groundwater whereas the lowest concentration was found in surface water collected from geomineral mine i-e 4.7ppm. The prescribed limit for copper is 2ppm. Although copper is an essential element for living organisms but excessive exposure can cause anemia, diarrhea in young children, abdominal pain, vomiting, headache, nausea, liver and kidney damage. Consuming water with elevated level of copper can prove to be dangerous for people with certain metabolic disorders.

Fig. 3. Geographical location of the study area.

Table 4 shows that all water samples were within the limit prescribed by national drinking water quality standards for lead. However the highest concentration of lead was found in KD wells mine surface water at 0.027 ppm. Lead is carcinogenic in nature and its exposure can cause miscarriages, brain damage, kidney damage, sperm production reduction and central nervous system damage.

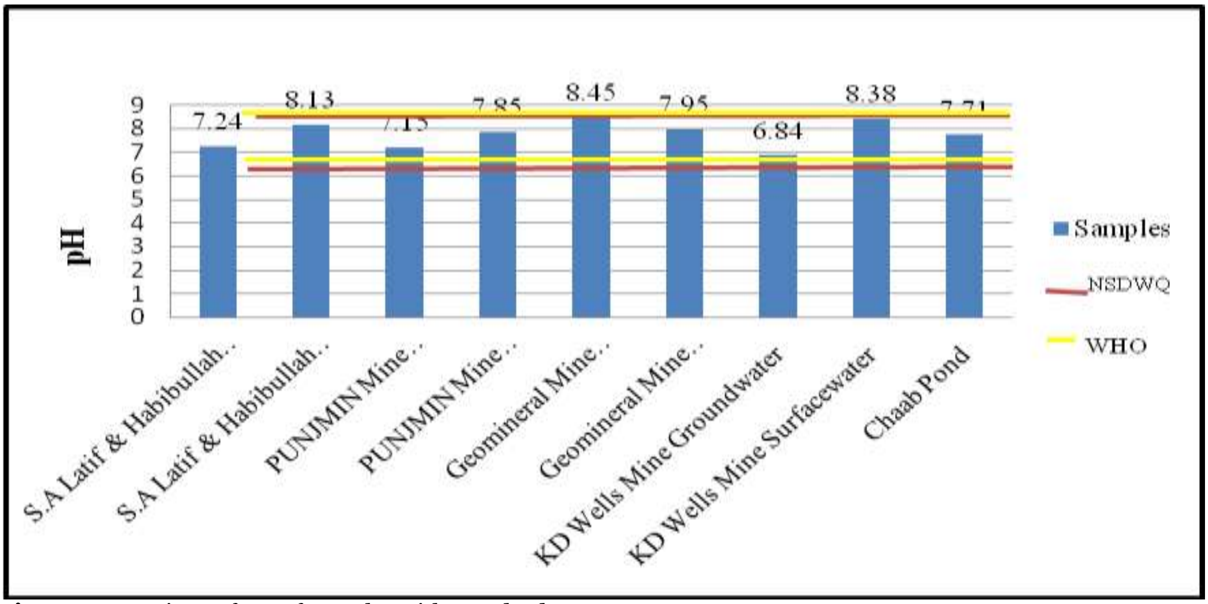

Fig. 4. Comparison of pH of samples with standards.

Significant amount of nickel was also detected in the collected samples as shown in table 4. Sample collected of ground water from geomineral mine contained highest concentration of nickel (30ppm). High concentration of nickel can cause damage to health of humans and livestock.

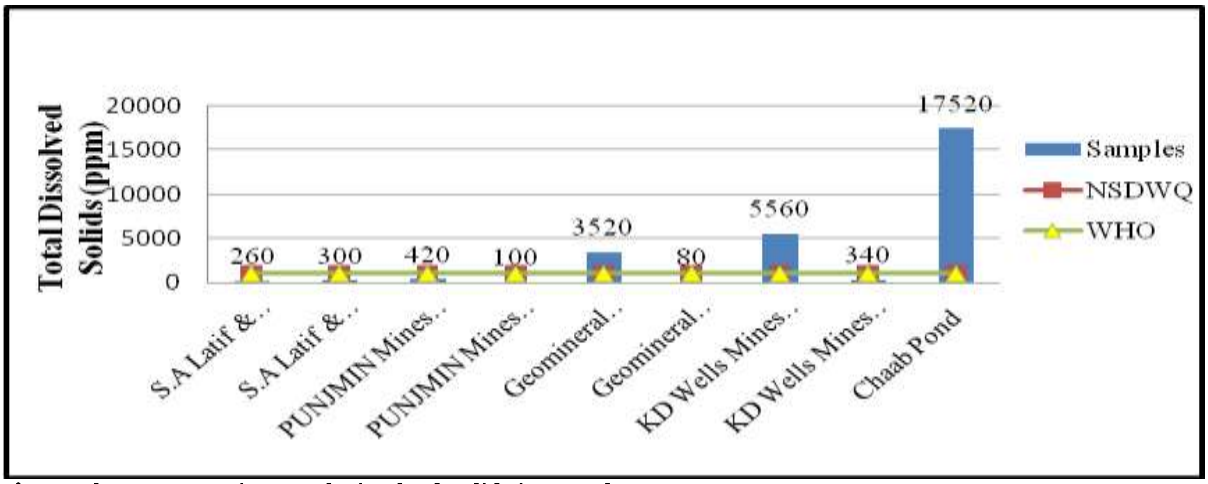

Fig. 5. The concentration Total Dissolved Solids in Samples.

Concentration of Iron in S.A. Latif & Habibullah mine groundwater sample was 12.25ppm where as its surface water had 14.95 ppm of Iron in it. In PUNJMIN groundwater sample iron was 8.95ppm and in surface water it was 8ppm. A very high concentration (36ppm) was found in groundwater of geo-mineral mine where as it is 8.1ppm in surface water. Groundwater sample from KD Wells mine had 5.5ppm of iron whereas its surface water contains 9.95ppm of iron.

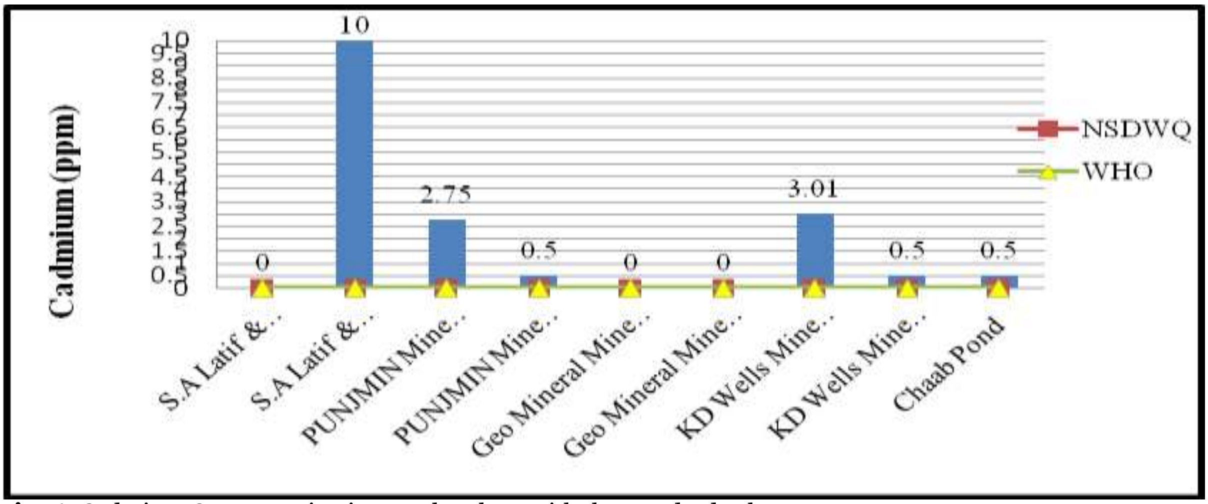

Fig. 6. Cadmium Concentration in samples along with the standard values.

The concentration of iron in chaab pond water was at 5.5ppm. Consuming high levels of iron can cause conjunctivitis, choroiditis and retinitis. If inhaled it can cause lung cancer. Other heavy metals such as Chromium, Zinc, Mercury and Manganese were below the detectable limit (BDL) in all samples. According to a study conducted previously the amount of manganese and iron was exceeding the drinking water quality limits in groundwater samples. The contamination of underground water aquifer is one of the major problems even if some plan or action has been taken to prevent it. Water from the abandoned mining site may have high level of total dissolved solids, heavy metals, changes in pH and temperature but this depends on the geochemical conditions of that area. Even if the water is neutral or towards the alkaline side it still has the potential to dissolve heavy metals in excess to the water quality standards. This can pose a serious threat to human health and environment as this water is then not fit for consumption (Chandra and Jain, 2013).

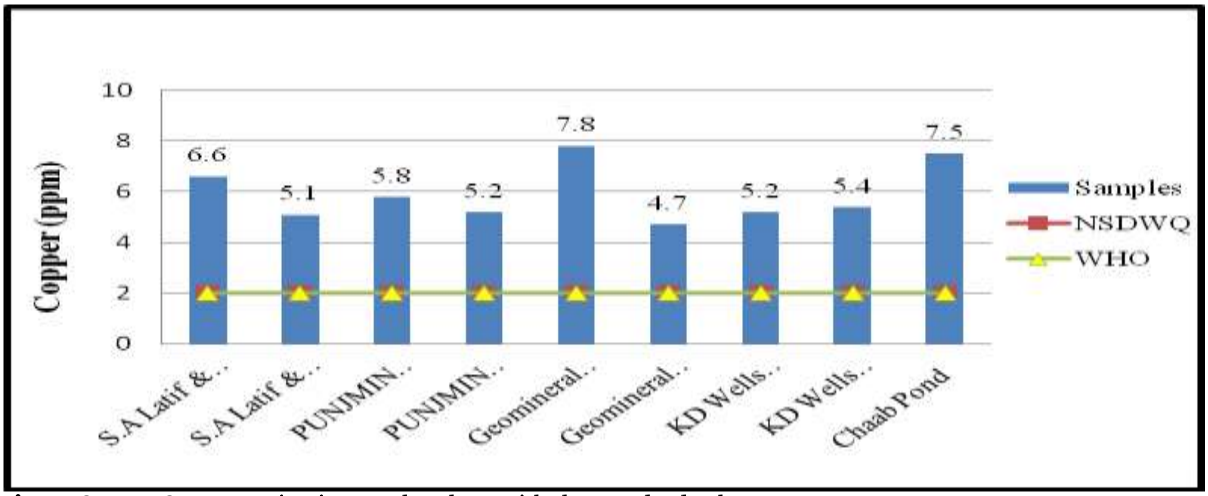

Fig. 7. Copper Concentration in samples along with the standard values.

The results shown in fig. 4 depicts that the pH of all samples collected from the mines groundwater and surface water have showed neutral to slightly alkaline nature and were in compliance with the standards.

Fig. 5 shows that TDS in most of the samples were under permissible limits of National Standards for Drinking Water Quality and World Health Organization standards except for geomineral mine groundwater, KD Wells mine groundwater and Chaab pond.

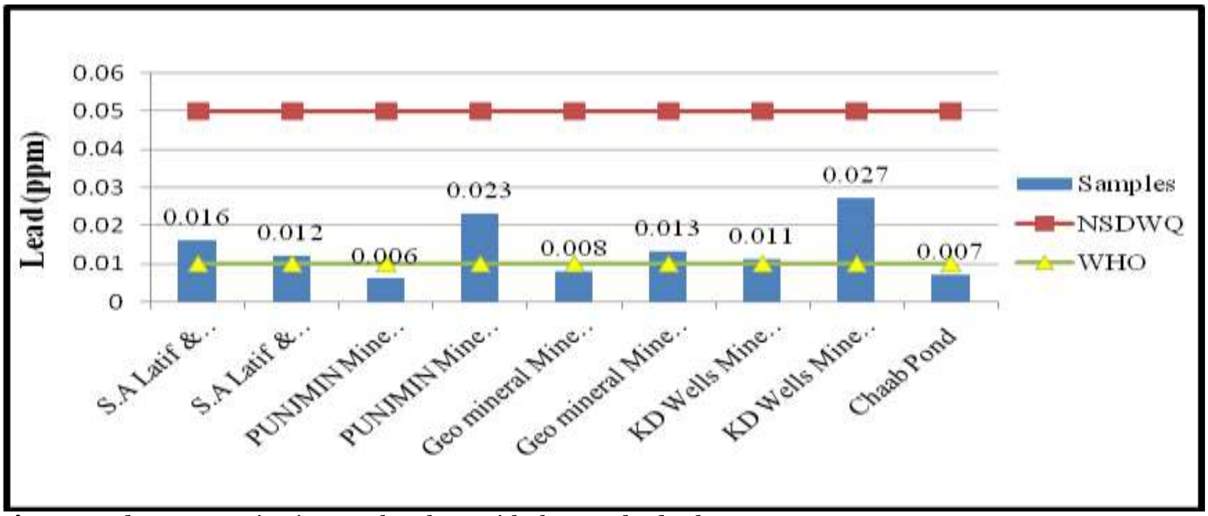

Fig. 8. Lead Concentration in samples along with the standard values.

As shown in fig. 6, concentration of cadmium was below detectable limit in three of the collected samples i-e S.A Latif & Habibullah mines groundwater, Geomineral mine's groundwater and surface water, All other samples exceeded given standards of NSDWQ and WHO.

The fig. 7 illustrates that the copper concentration in all the collected samples was very high and not meeting the standards prescribed by Government of

Pakistan for drinking water quality and World Health Organization.

In fig. 8, Lead concentration was high in different samples and lacked compliance with World Health Organization standards. Fig. 9 depicts that the collected samples also contain significant amount of nickel in them. The highest concentration was found in Geo mineral mine i-e 30ppm.

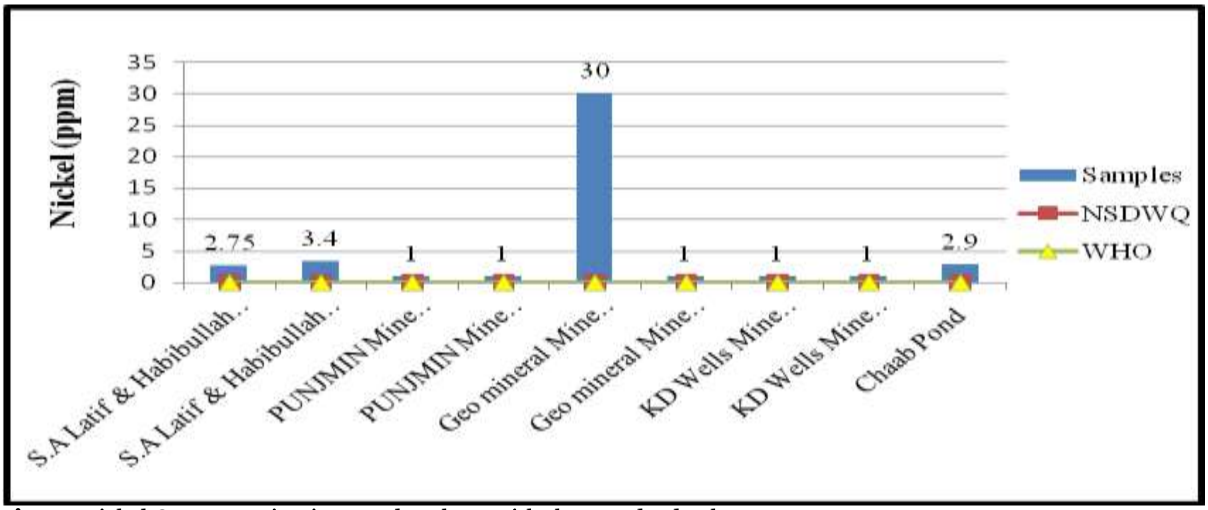

Fig. 9. Nickel Concentration in samples along with the standard values.

Comparison of Chaab pond water quality with recreational water standards

Chaab pond contains water that drains from the surrounding mines during the monsoon season. Chaab pond is used by the people for recreational purposes. In order to analyze its water quality the parameters tested were pH, electrical conductivity, DO, TDS, BOD. Some heavy metals such as lead, cadmium, chromium, zinc, mercury and copper were also tested and compared with recreational water quality standards by WWF. Comparison showed that DO concentration, pH, lead concentration were within the standard values prescribed by WWF as shown above in tables 3 and 4. The results showed that pond water's electrical conductivity greatly exceeded the standard value of WWF.

Other parameters such as TDS, BOD, Cadmium and Copper concentrations also showed their non-compliance with the recreational standards. The lab analysis revealed that chromium and zinc were not present in the samples as their values were below detectable limits, however in case of mercury; it was only present in two of the samples and was within the given standard value. The heavy metals analysis of river sediments and coal in coal city of Nigeria showed that manganese was in highest concentration about 0.256 to 0.389mg/kg and lead was in the lowest amount about 0.013 to 0.017mg/kg. (Adaikpoh *et al.*, 2005).

Conclusion

The study showed that groundwater and surface water of the research area contained very high levels of Cu ranging from 4.7 ppm to 7.8 ppm and thus has exceeded the allowed limit greatly. The water also contains significant amount of Ni ranging from 1ppm to 30ppm. Fe was also present in all the samples in very large quantity which is 5.3 ppm to 36 ppm. Although Fe is an essential element for living organisms but too much of something can also lead to a number of problems. All samples contained Pb but only a few exceeded the limit. The water of Chaab pond is also not safe for recreational purposes as the BOD, conductivity; Cd and Cu concentrations were very high and also exceeded the standards for recreational waters by WWF. Results also showed high levels of fecal contamination in all the samples which can have harmful effect on human health.

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