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Quality and Environmental Impact Assessment of Coal Deposits of Punjab Pakistan

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ABSTRACT
Major coal fields in Punjab Province are located in the Salt and Surghar ranges, whose collective reserves are 235 million tons. Representative coal samples were collected from Makarwal, Kallar Kahar and Dandot for assessment of quality and its impact on environment during combustion. The coal was classified as sub-bituminous type on the basis of proximate analysis. Average measured calorific values were noted 6801, 5624 and 6415 Btu/lb for Makarwal, Kallar Kahar and Dandot samples respectively. Moderate moisture, volatiles, fixed carbon and low ash designate it as suitable material for electric generation and cement manufacturing. The average sulfur content of all samples was appeared as 5.13%, which is high for power generation and other allied industries. The combustion of this coal may pose threat to the environment in the region due to the presence of high sulfur and other trace elements like Al, Cr, Fe, Zn, Mn, Cu, Sn, and Ni in appreciable quantities. Appropriate measure is essential to substantially reduce sulfur and these trace elements before using it in the power generation plants and other industries of Pakistan

Keywords: Punjab Coal deposits, Salt Range, Coal Quality, Environmental Impact, Proximate analysis, heavy metals

1. INTRODUCTION
The continuously increasing energy crises in Pakistan have triggered the need for alternate energy sources by industries to produce electricity. Currently, in Pakistan, coal hardly contributing ~0.1% in power generation. It is important to note that the share of coal in the electricity generation in India is more than 68%, in spite of the fact that India has very low reserves of lignitic coal (4.5 Billion Tons). Present government has planned to utilize coal for cheap power generation. Pakistan has huge reserve (185 Billion Tons) of coal, out of which 235 million tons are present in Punjab[1]. The main coal fields of Punjab are located in Salt (213MT) and Surghar (Makarwal) ranges (22MT). The coal deposits of Salt and Surghar ranges are classified as sub-bituminous, and the heating value ranges from 9,472 to 15,801 Btu/lb. It has low ash and high sulfur and is suitable for power generation after proper desulfurization.

There are two major concerns about coal usage as fuel for power generation. One is the coal quality while other is environmental consideration[2]. Quality of coal is very important for installation of a cost-effective (low capital and operating cost) quality power plant[3]. As far as the environmental impact is concerned, the combustion of coal is the main cause of many atmospheric fugitive emissions like CO, CO_2, SO_2, H_2S and NO_x. Coal is a compressed organic matter containing carbon as major element[4]. It is worth mentioning that virtually every element in the periodic table is present in the coal. Coal also contains many toxic metals (Ti, Sr, Mn, V, As, Ni, Pb, Hg, Cr etc.) in appreciable quantities. Trace elements are becoming more important because of restrictions on the emission of air toxins and the disposal of waste ash. In many countries legislation has been introduced limiting the discharge of environmentally sensitive trace elements[5, 6]. More attention is required to focus on the levels of trace elements in power station feed stocks. This is likely to have a significant impact on the world coal export market. The extraction of coal from its geological sources involves the production of acid mine drainage from coal mines. For oil and gas there is a risk of contamination of terrestrial and aquatic systems during extraction from accidental leaks and spills. It is, therefore, necessary to acquire accurate, reliable and quantitative information about the concentration and modes of occurrence of chemical elements, especially heavy metals in feed coal and coal combustion products.

Present study elaborates the rank of coal deposits in Salt and Surghar ranges by proximate analysis and calorific values. Current study is beneficial for designing electric power generation plants in the country. Assessment of various trace elements may provide guideline for better environmental conservation.

2. EXPERIMENTAL
Sites for sampling were selected to represent different parts of the Salt and Surghar ranges of Punjab Province (Fig. 1). All the samples were collected from different coal mines situated between Salt and Surghar range. Eight samples were collected from Makarwal region (M1 to M8); 8 samples from Kallar Kahar (K1 to K8) and 6 samples from Dandot area (D1 to D6). Standard ASTM methods were adopted for proximate analysis of coal samples. Ash[7] and volatile matter[8] were estimated gravimetrically. Moisture content was measured using Moisture Analyzer, Sartorius MA 50[9].

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Total sulfur was analyzed using Eschka method[10]. Calorific values were obtained from Adiabatic Bomb Calorimeter (Parr 1241).

Coal samples were crushed and pulverized to fine powder. A known weight of air dried -200 mesh sample was decomposed by concentrated hydrofluoric acid (HF), concentrated nitric acid (HNO_3), and 3N hydrochloric acid

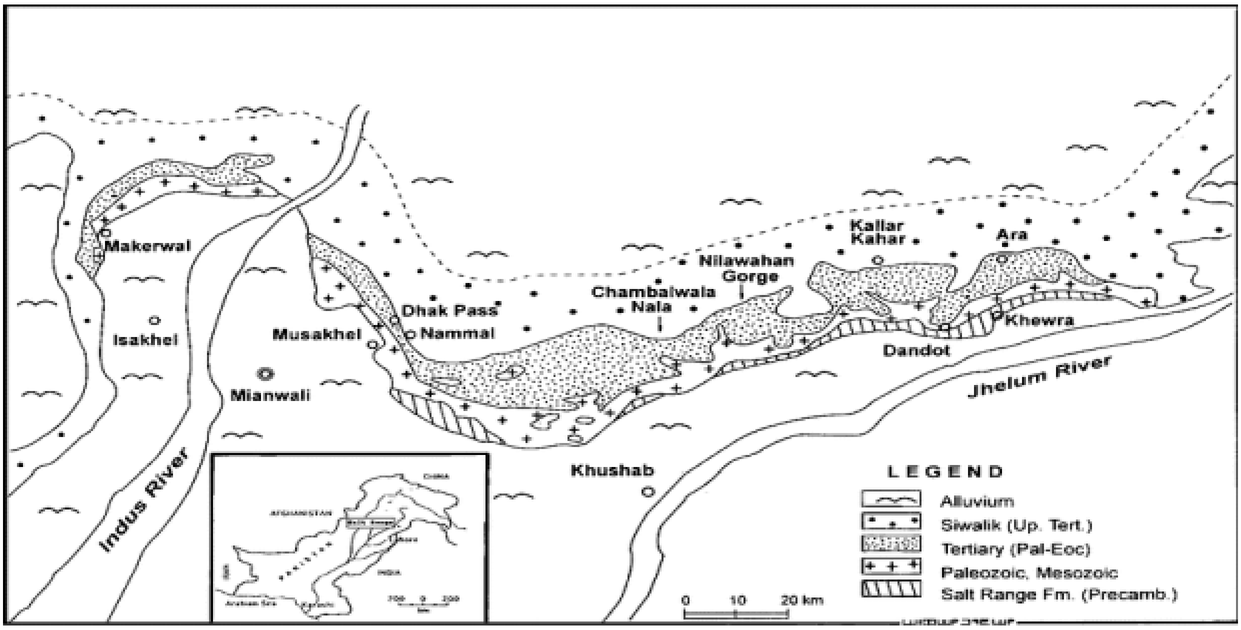

Fig-1: Map of the study area showing sample sites

(HCl), in the Teflon beakers and the final stock solution of 50 mL volume was prepared by using the method of Jeffery and Hutchison[11]. After preparing the stock solutions of all coal samples, elements were estimated in test solutions by using Atomic Absorption Spectrophotometer (Perkin Elmer, AA Analyst 100).

3. RESULTS AND DISCUSSION

3.1 *Proximate analysis*

3.1.1 *Moisture*

In the analyzed samples, moisture was found in the range of 3.12 - 5.59% with an average value of 4.41% in Makarwal, 1.33-7.8 % in Kallar Kahar, with an average value of 5.99%, while 3.07-6.69 % with an average value of 5.50 % in Dandot coal field (Table 1, Fig. 2). Moisture is very important for the determination of quality of coal. Total moisture in coal includes the inherent and surface moisture, which directly affects its specific energy and efficiency of the boiler due to loss of latent heat of water accompanied with the flue gas. An increase of 1% moisture drops boiler efficiency by 1%. A greater volume of coal is also required, affecting the operating and maintenance cost and capital cost of the plant. The dust collecting plant, ash plant and boiler plant are also affected by the increase in moisture of the coal. An increase of 1% of moisture in design coal increases the capital cost of the power plant by 4%[2].

Table-1: Proximate analysis (Mean, Minimum, Maximum) of coal from study area.

Parameter	**Makarwal Coalfield**			**Kallar Kahar Coalfield**			**Dandot Coalfield**		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Total Moisture (%)	4.41	3.12	5.59	5.99	1.33	7.85	5.50	3.07	6.69
Ash (%)	28.37	11.26	41.15	31.65	13.44	53.83	30.46	23.4	36.06
Volatile matter (%)	33.89	25.05	43.79	31.38	22.76	34.57	34.64	31.23	37.78
Sulfur (%)	6.02	3.61	10.82	4.60	3.15	8.84	4.79	1.26	8.08
Fixed Carbon (%)	33.39	24.02	40.93	30.96	17.83	45.3	29.36	24.77	34.75
Heating Value (Btu/lb)	6801	4736	8012	5624	2533	10102	6415	4650	8006

3.1.2 *Fixed Carbon*

Fixed carbon provides a rough estimate of heating value of coal. It consists mostly of carbon but also contains some hydrogen, oxygen, sulfur and nitrogen. In coal samples from Makarwal coal, fixed carbon was found in the range of 24.02-40.93% with an average value of 33.39%. In Kallar Kahar and Dandot samples values for fixed carbon were obtained in the range of 17.83-45.30% and 27.77-34.55%, with an average value of 30.96 and 29.36% respectively. The samples which showed high calorific value also consider to contain high value of fixed carbon (Table 1, Fig. 2).

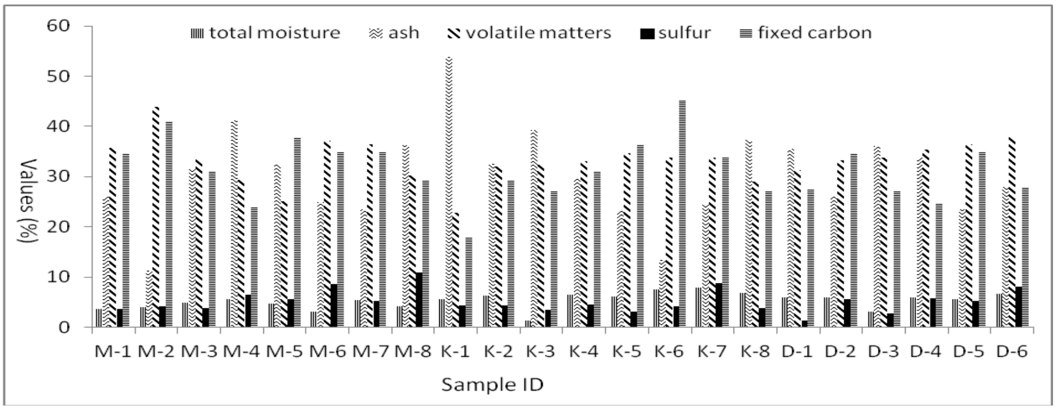

Fig-2: Comparative study of proximate analysis (%) among coal samples collected from study areas
Samples collected from Makarwal (M1 to M8), Samples collected from Kallar Kahar (K1 to K8) and Samples collected from Dandot (D1 to D6)

3.1.3 *Ash Content*

Ash is ranging from 11.26- 41.15%, 13.44-53.58% and 23.40-36.06% with an average value of 28.37%, 31.65% and 30.46% in Makarwal, Kallar Kahar and Dandot samples respectively (Table 1, Fig. 2). Ash content has an adverse effect on the power plant and its costs. An increase in ash content results in a direct decrease of specific energy. It then requires a greater quantity of coal to be handled by the coal plant, boiler, electrostatic precipitators and ash plant, and results in a larger and costlier plant and increased cost. Ash is responsible for erosion problems in boiler pressure parts and ducts and loss of availability. The effects of a 1% increase in ash content in coal increases operations and maintenance cost and plant costs by US$ 0.2 million per year and capital costs by 4%, whereas it reduces plant availability. The composition of ash determines its slugging and fouling effects, its abrasiveness and coating of heating surfaces of the furnace and convection areas of boiler. The recommended maximum ash content for the steam coals are up to 20% and a maximum of 10-20% for coking coal[12].

3.1.4 *Volatile Matter*

The specific energy is dependent on composition of the coal, indicated by the ultimate analysis, and is adversely affected by the moisture and ash content. The volatile matter is of key interest in determining the coal's reactivity and ignitability. Low volatile coal requires long burnout time and ignition support at certain loads. Coal having values less than 18% volatile would requires special boilers using down- shot firing to provide turbulence and longer furnace residence time. In the studied samples the volatile matter was found in the range of 25.05-43.79, 22.76-34.57 and 31.23-37.78% in Makarwal, Kallar Kahar and Dandot samples respectively. The average values for volatile matter are found as 33.89, 31.38 and 34.64% respectively in Makarwal, Kallar Kahar and Dandot coalfields samples (Table 1, Fig. 2). There is no significant difference in average volatile matter of Makarwal, Kallar Kahar and Dandot coal samples.

3.1.5 *Sulfur*

The sulfur content is also an important factor in coal quality, mainly for corrosion and environmental reasons. Coal with low sulfur content can be used without a desulphurization plant. In analyzed coal the values for sulfur were obtained in the ranges of 3.61-10.82, 3.15-8.84% and 1.26-8.08% with average sulfur contents as 6.02%, 4.60%, and 4.79% in Makarwal, Kallar Kahar and Dandot samples respectively. All the coal from these three locations have high sulfur content (Table 1, Fig. 2).

The total sulfur content in the steam coal used for power generation should not exceed than 0.8-1.0%.For cement industry 2% max sulfur is acceptable and for coking coal maximum 0.8% is required, because higher values affect the quality of steel[12]. The coal from these coalfields may have higher SO_2 emission as flue gases to the environment and may also cause corrosion and fouling of boiler tubes. In order to estimate the amount of SO_2 produced daily from the power station, it is necessary to know the calorific value, sulfur and ash contents of the coal and power station heat rate. According to world bank group a 500 Mw plant using coal with 2.5% sulfur, 16% ash and a calorific value of 12898 btu/lb will emit 200t SO_2, 70t NO_2, 500t fly ash, 500t solid waste and 17 (GWh) of thermal discharge per day[13]. In the studied samples all the coal on average having more than 2.5% sulfur, therefore, the SO_2 release will be more than 200t per day, if 500t MWe of coal from these coal fields are used. These coals therefore need to be desulfurized before their use.

3.1.6 *Combustion Properties*

Calorific value is the measure of energy content of coal. The calorific values of coal samples are given in Table 1& Figure 3. It is clear from the table that the calorific value varies from 4736-8012 Btu/lb with average value of 6801 Btu/lb in Makarwal sample; 2533-10102 Btu/lb Kallar Kahar samples with average value 5624 Btu/lb and 4650-8006

Btu/lb with an average value of 6415 Btu/lb in Dandot samples (Table 1, Fig. 3). The coal which contains calorific value more than 10080 Btu/lb is considered as grade A coal, while less than 2340 Btu/lb is considered as grade G coal.

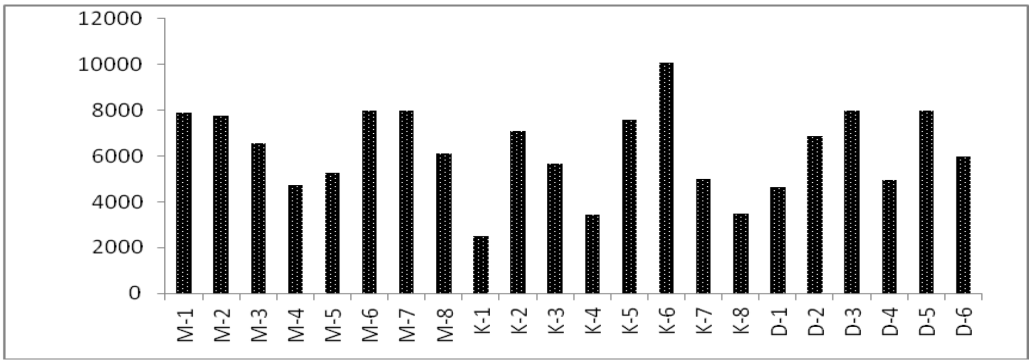

Fig-3: Comparison of heating value (gross calorific value, Btu/lb) of different coal samples
Samples collected from Makarwal (M-1 to M-8), Samples collected from Kallar Kahar (K-1 to K-8) and Samples collected from Dandot (D-1 to D-6)

3.1.7 *Trace elements*

The concentration of aluminum is highly variable in all the samples. In Makarwal coalfield it is ranging from 5795-16511 mg/kg, while 6195-21283 and 1200-17607 mg/kg in Kallar Kahar and Dandot coal fields. The average Al content was found 8597 mg/kg, 13108 mg/kg, and 9585 mg/kg in Makarwal, Kallar Kahar and Dandot coal fields respectively (Table 2, Fig. 5). The highest Al content found was 16511 mg/kg in Makarwal, 21283 in Kallar Kahar and 1707 in Dandot samples respectively. All the coal samples contain very high content of Al, which shows a potential threat for environmental pollution[14].

Table-2: Elemental concentrations (Mean, Minimum, and Maximum) of coal of study area (mg/kg), ND =Not detected.

	Makarwal Coalfield			**Kallar Kahar Coalfield**			**Dandot Coalfield**		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Al	08597	05795	16511	13108	06195	21283	09586	01200	17607
Cr	2067	1182	6940	2375	1234	8906	1635	1534	1705
Fe	17027	04180	33889	11041	06009	32463	08855	05914	14576
Zn	0213	0145	0299	0826	0417	1339	0687	0306	0159
Cu	114	069	159	108	033	160	105	052	187
Cd	0.180	0.005	0.400	0.272	0.110	0.400	0.290	0.200	0.400
Pb	13	04	29	10	05	15	16	08	27
Mn	ND	-----	-----	29.12	00.00	48.00	80.33	52.00	107.0
Sn	0957	0567	1347	1366	1008	1620	1388	1333	1444
Ni	393	190	597	473	310	582	375	319	675
Co	ND	-----	-----	ND	-----	-----	ND	-----	-----
Ca	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mg	0667	0161	1507	1775	1071	4175	1680	1644	1764
Na	02058	00000	02058	02316	00000	02316	08507	01041	15503
K	1299	0320	3131	1659	0597	4951	1342	0875	1780

The coal samples did not show a large variation in the concentration of chromium, as it is in the range of 1182-6940 mg/kg, 1234-8906 mg/kg and 1534- 1705 mg/kg in Makarwal, Kallar Kahar and Dandot respectively (Table 2, Fig. 5). Chromium is very important element with respect to environmental concerns because of its possible toxicity. This value is very much higher than the mean value of coal elsewhere in the world[15], which is a potential environmental threat (Table 3).

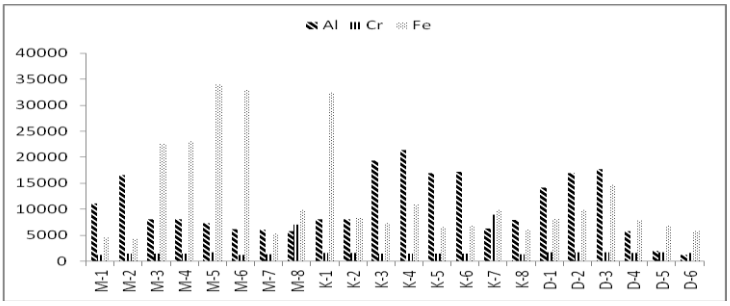

Fig-5: Comparison of results for heavy metals (Al, Cr, Fe) of different coal samples from Makarwal, Kallar Kahar and Dandot (mg/kg)

Table-3: Worldwide ranges (mg/kg) of elements in coal (after, SWAINE 1990). NA = Not Available

	Mean	Minimum	Maximum
Al	NA	NA	NA
Cr	20.00	0.50	060.00
Fe	NA	NA	NA
Zn	50.00	05.00	300.00
Cu	15.00	0.50	050.00
Cd	05.00	0.10	003.00
Pb	40.00	2.00	080.00
Mn	70.00	5.00	300.00
Sn	NA	NA	NA
Ni	20.00	0.50	050.00
Co	5.00	0.50	030.00
Ca	NA	NA	NA
Mg	NA	NA	NA
Na	NA	NA	NA
K	NA	NA	NA

A vast variation was observed in the concentration of iron in all coal samples. The concentration of Fe varies from 4180-33889 mg/kg in Makarwal, 6009-32463 mg/kg in Kallar Kahar and 5914-14576 mg/kg in Dandot samples. The samples from Makarwal coalfield showed highest Fe content than Kallar Kahar and Dandot samples (Table 2, Fig. 5). Iron is associated with sulphide and carbonates. The mean worldwide value for Fe is not available, so it cannot be compared with coal elsewhere in the world.

One of the most serious effects of underground coal mining has been the escape of polluted water from both old and current mine workings. The mineral iron pyrite and marcasite (FeS_2) are commonly present in coal and in coal-bearing sequences, and these are reactive to atmospheric oxygen. The initial products of oxidation are ferrous and ferric Sulphate, sulphuric acid and hydrated ferric oxide, with the exception of ferric oxide. These products are soluble in water and in turn react with clays and carbonate minerals to form Al, Ca, Mg and SO_4. Water flooding in to the abandoned mine areas containing large quantities of sulphide minerals will rapidly become contaminated. This all pollute the underground water, which contains largest quantities of Fe and other dissolved metals[13].

No vast variation was observed in the concentration of zinc of Makarwal coalfield samples. Zinc was found in the range of 145-299 mg/kg with an average value of 213 mg/kg. Samples collected from Kallar Kahar, Zn was obtained in the range of 417-1339 mg/kg while in Dandot samples in the range of 159-306 mg/kg. Some samples of Kallar Kahar coal field showed unusual high zinc content (K2, K4 and K6 having Zn 1181, 1332 and 1339 mg/kg respectively) (Table 2, Fig. 4). Samples of Makarwal and Dandot showed values of Zn less than the values obtained elsewhere in the world, while many samples collected from Kallar Kahar showed higher values of zinc than mean worldwide values (Table 3).

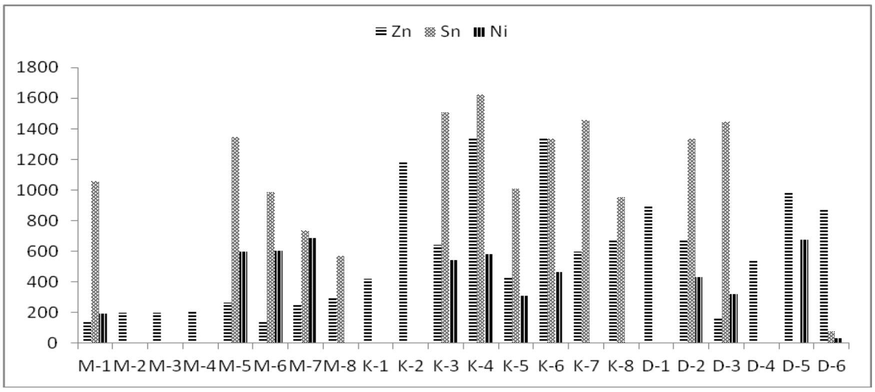

Fig-4: Comparison of results for heavy metals (Zn, Sn, Ni) of different coal samples from Makarwal, Kallar Kahar and Dandot (mg/kg)

Large variations were observed in the concentration of Cu in all coal samples. Copper was found in the range of 69-159 mg/kg in Makarwal, 33-160mg/kg in Kallar Kahar and 52-187 mg/kg in Dandot samples. The average Cu concentration was found 114 mg/kg, 108 mg/kg and 105mg/kg respectively. The mean worldwide value of Cu is 15mg/kg (Table 2, Fig. 6). All the samples from these coal fields showed very high concentration of Cu as compare to the values obtained anywhere else (Table 3).

In all coal samples obtained from Makarwal, Mn was not detected. Two samples from Kallar Kahar coal field also did not show presence of Mn. One sample from Dandot coal field showed unusual high concentration of Mn

(107mg/kg) when compared with other samples. The mean value of Mn in Kallar Kahar coal was found 34 mg/kg, and 80 mg/kg in Dandot, which are lower than the coal elsewhere in the world (Table 3, Figure 6).

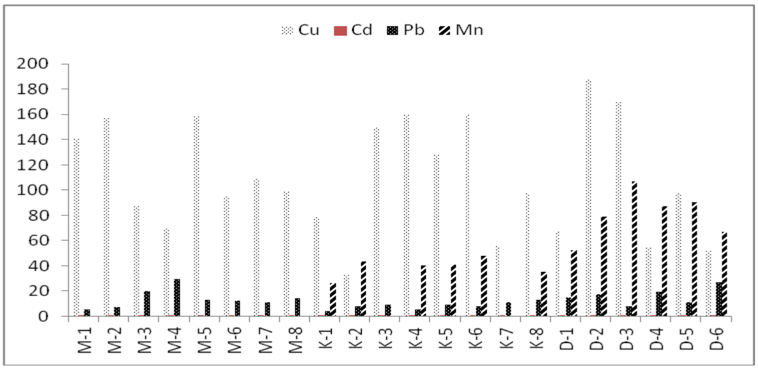

Fig-6: Comparison of results for heavy metals (Cu, Cd, Pb, Mn) of different coal samples from Makarwal, Kallar Kahar and Dandot (mg/kg)

The presence of Ni in the coal may be due to sulphide phase[16], as well as the inorganic or organic matter[17]. The mean value for Ni is 20 mg/kg with a range of 0.5-50 mg/kg in coal elsewhere in the world[15]. In Makarwal Ni was not detected in four samples. Average Ni was found 519 mg/kg in Makarwal coal field. Same trend was observed in Kallar Kahar, four samples did not show Ni, while the average value in half samples is 473 mg/kg. Two samples from Dandot did not show Ni content. The average Ni in other Dandot samples is 364 mg/kg. One sample from Dandot showed very low Ni content (33 mg/kg) (Figure 4, Table 2).

Cobalt was absent in all analyzed samples. Only two samples from Makarwal showed presence of tin. In Kallar Kahar samples it was absent in four samples. The average Sn content in other samples is 1366 mg/kg. Only two samples (D2 and D3) from Dandot coal field showed its presence (Table 2, Fig. 4).

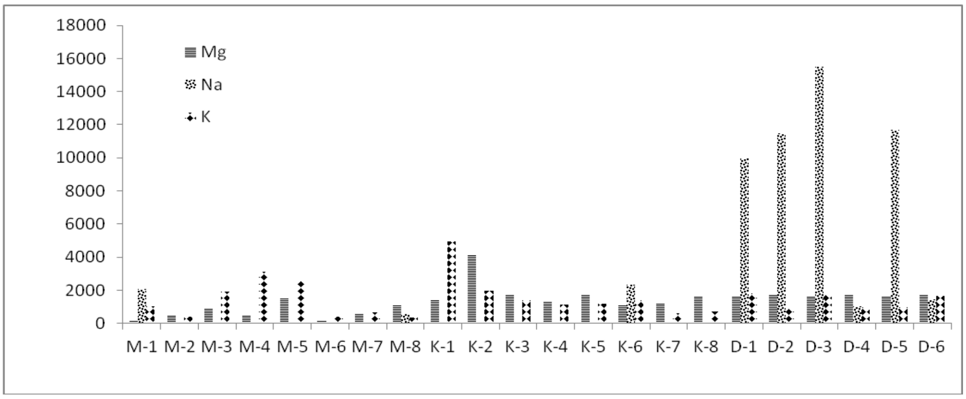

Fig-7: Comparison of results for light elements of different coal samples from Makarwal, Kallar Kahar and Dandot (mg/kg)

Most of the samples from Makarwal and Kallar Kahar also showed the absence of sodium. One sample of Makarwal (M1, 2058 mg/kg) and one sample from Kallar Kahar (2316 mg/kg)showed very high sodium (Fig. 7). All samples from Dandot showed the presence of Na, ranging from 1041-15503 mg/kg, with mean value 8507 mg/kg. The mean worldwide value for Ca in coal is 0.5 mg/kg. In all samples Ca was not detected in mg/kg which shows the absence calcite and dolomite[18]. Magnesium was found in varying ratio from 161-1507 mg/kg, 1071-4175mg/kg and 1644-1764 mg/kg in Makarwal, Kallar Kahar and Dandot samples respectively. The average values observed were 667, 1775 and 1680 mg/kg in these three coal fields respectively (Fig. 7). No vast variations were observed in the amount of K in all coal samples except three samples from Makarwal (M3, M4 and M5, 1913 mg/kg, 3131mg/kg and 2539 mg/kg respectively) and one from Kallar Kahar (K1, 4951 mg/kg) showed high amount of K as compared to other samples (Table 2, Fig. 7).

4. CONCLUSIONS

Coal is an important part of world energy supply due to its domestic availability and abundance, particularly in the scenario of present energy crisis in Pakistan. The proximate analysis of collected coal samples from Salt and Surghar ranges show average moisture content is 5.26%, fixed carbon 31.23%, ash 30.16% and volatiles 33.03%. Average calorific values of Makarwal, Kallar Kahar and Dandot samples were measured 6801, 5624 and 6415 Btu/lb respectively. Based on amount of different parameters of proximate analysis and heating values, the rank of the coal is deduced as Sub-bituminous type and is suitable material for electric generation, cement manufacturing and other allied industries. The average sulfur content was noted 6.02%, 4.60%, and 4.79% in Makarwal, Kallar Kahar and Dandot samples respectively. The value is much higher for power plants (1%) and cement industry (2%), this will cause environmental pollution. There are many problems related with the use of coal, as its quality impact on environment due to emission of environmentally hazard gases and toxic elements. High amount of Al, Cr, Fe, Zn, Mn, Cu, Sn, and Ni in the coal samples of study area may pose threat to the environment of the region. It is suggested that the coal needs cleaning and desulfurization before use it as fuel.

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