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Geochemical impact assessment of produced water of Sadqal oil and gas field on the soil surrounding the storage ponds in Fateh Jang area, Punjab, Pakistan

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Abstract

Composite soil samples were collected at different distance from eastern, western and southern sides of the produced water ponds of Sadqal oil and gas field Fateh Jang, Punjab, Pakistan to assess the anions, cations and heavy metal concentrations. The concentrations of sodium (Na^{+}), potassium (K^{+}), calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^{-}), florid (F^{-}), sulfate (SO_4^{-2}), nitrate (NO_3^{-}) and nitrite (NO_2^{-}) were determined by using Ion chromatography (Metrohm, 800 series). Heavy metal concentrations i.e. chromium (Cr), manganese (Mn), cadmium (Cd), zinc (Zn), copper (Cu), lead (Pb), nickel (Ni) and iron (Fe) were analyzed using Atomic absorption spectrophotometer. The results were compared with reference soil sample of the study area. It was found that maximum parameters of soil samples collected from the surrounding of ponds were high in concentration as compared to that of reference soil samples. A consistent decrease of most of the cations, anions and heavy metals was noticed with increasing distance from the ponds. The soil proximal to the ponds is highly contaminated and can pose health related threats to the human beings and may also cause damaging effects on the plants of the study area.

Keywords: Geochemistry; Sadqal field; Oil and Gas; Produced water; Anions; Cations; Heavy metals.

1. Introduction

Soil, an important environmental medium, is exposed to a number of pollutants including toxic heavy metals released from various natural and anthropogenic activities. Consequently, heavy metal contaminated soil has the potential to pose severe health risks to humans as well as other living creatures of the aquatic and terrestrial ecosystem. These heavy metals enters the body through various routes such as direct ingestion of contaminated food, water and with contaminated soil contact (Soodan et al., 2014). Soil contamination with heavy metals is a major threat to ecological integrity and human well-being due to discharge of untreated urban and industrial wastewater (Mahmood and Malik, 2014). Toxic metals can enter the human body by consumption of contaminated food crops, water, inhalation of dust or dermal contacts (Cambra et al., 1999) .

Heavy metal accumulation in soil is one of the most serious environmental concerns of the present day. Toxic heavy metals have potential effects on human, animals and plants life. Metals are non-biodegradable and are considered major environmental pollutants resulting in cytotoxic, mutagenic and carcinogenic effects in animals (Al-Othman et al., 2011; More et al., 2003). Soil irrigated by wastewater results in accumulation of heavy metals (Cd, Zn, Cr, Ni, Pb, and Mn) in surface soil. When the capacity of the soil to retain heavy metals is reduced due to repeated use of wastewater, soil can release heavy metals into ground water or soil solution available for plant uptake. Thus, wastewater irrigation is known to contribute significantly to the heavy metals of soils (Mapanda et al., 2005; Singh et al., 2004) and causing a major potential environmental risk (Chary et al., 2008).

Uncontrolled heavy metal input to soils is undesirable, because once accumulated, it is extremely difficult to remove these metals. This situation may subsequently leads to i) toxicity to plants grown on contaminated soils, ii) absorption by crops resulting in heavy metals in plant tissues which may be harmful to the health of humans or animals, and iii) transport from soils to groundwater or surface water (Murtaza et al., 2010). Heavy metal contamination of soil resulting from wastewater irrigation is a cause of serious concern due to the potential health impacts of consuming contaminated produce. concluded that the use of treated and untreated wastewater for irrigation has increased the contamination of Cd, Pb, and Ni in edible portion of vegetables causing potential health risk in the long term from this practice.

Industrialization and poor environmental management in developing countries like Pakistan have increased the environmental problems. Industrial wastes and chemicals in the terrestrial environment clearly pose a significant risk to the quality of soils, plants, natural waters and human health. The main objective of the study was to assess the levels of soil contamination present around the produced water ponds of Sadqal oil and gas field, Fatehjang, Punjab, Pakistan.

1.1. Study area

This study was conducted in Fateh Jang Sadqal oil and gas field, near Rawalpindi Islamabad (Fig. 1).

The study area was selected with a framed hypothesis that the pumped out water called as produced water obtained from the oil and gas wells of Oil and Gas Development Company Limited (OGDCL) has impacts on the surrounding environment. It lies between latitude 33º 34' N and longitude 72º - 45'E with different types of land uses. The main land use is rain fed agriculture and the non-cultivated area consisting of natural vegetation like forest, shrubs, grasses and the wastelands. Mainly two seasons alternate each other and rain fall is maximum during the summer season. The mean seasonal rainfall in summer and winter seasons ranges from 300-500 mm and 250-300 mm, respectively and the temperature ranges from 5-30°C (Roohi et al., 2004; Shaheen et al., 2008).

The OGDCL has started exploration and production activities in Sadqal area for more than two decades. Wastewater is released one kilometer away from the plant into the ponds located near residential area. Moreover, excess water over flows from the pond and make its way into a stream. The excessive wastewater seepages from the ponds thereby contaminating the nearby soil.

2. Methodology

2.1. Soil samples collection

Composite soil samples (≈ 1 kg) from each point was collected at a depth of 0-20 cm in self-locking polythene bags from produced water ponds area at various distances such as 0, 30, 60, 90 and 120 meters in different directions (i.e., East, West and South) from the top soil. A monolith of 10 × 10 × 20 cm was dug for the collection of soil.

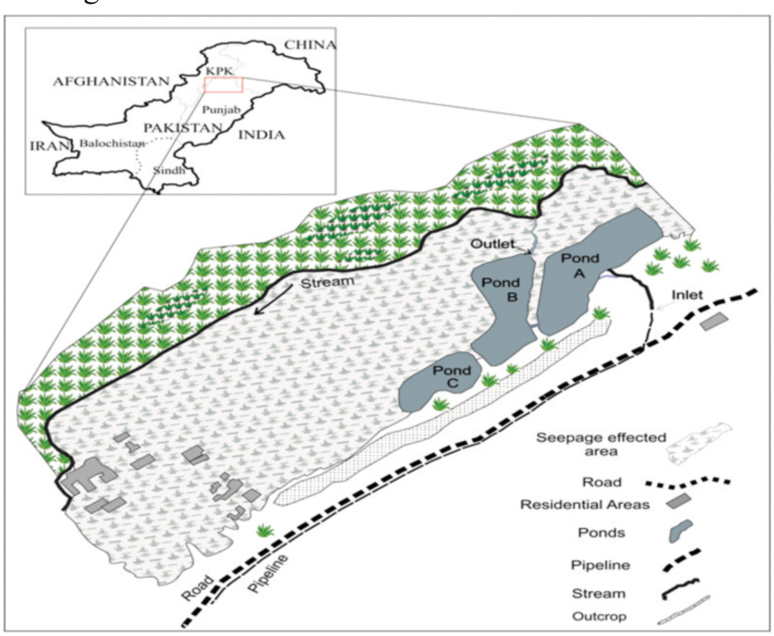

Fig. 1. Location map of the study area.

These soil samples were mainly collected to analyze the impacts of wastewater effluents on surrounding land. The reference soil samples were collected from the soil lying more than 5 km away from the produced water ponds where the effect of the contamination from the produced water ponds was not possible. The analyses of reference soils were carried out for comparison.

In order to avoid contamination, plastic spatula was used for collection of samples. Soil samples were air-dried and organic matters were removed. Each sample was homogenized and then representative portion was selected by quartering and coning. This portion was then used for further analysis. The dried soil samples were mechanically ground to obtain less than 2mm particle size. The powered samples were stored in air tight bottles and kept in an oven at 110 °C for two hours to remove the moisture.

2.2. Analysis of anions and cations

Soil samples (0.5 g) were mixed with 100 ml of deionized water. This mixture was shaken vigorously and then filtered through a 0.45 µm Millipore filter paper. Further, cations and anions were analyzed using Ion Chromatograph (Metrohm, 800 series) equipped with anion self-regenerating suppressor, a dual-piston pump, a DS6 conductivity detector and Metrosep A Supp5-250 separating column (4 x 250 mm). 3.2 mM sodium carbonate and 1 mM sodium bicarbonate solution was used as eluents for detection of anion, while 50 mM sulfuric acid was added as a regenerating agent. The flow rate was set as 0.70 ml/ minute, temperature as 30˚C, pressure as 11.9 Mpa and the injection volume as 500 µL. Similarly, for cations, column Metrosep C 2-250 (4.0 x 250 mm) was used. 4mM tartaric acid, 0.75 mM/L Dipicolinic acid solution was used as eluents and also 50 mM sulfuric acid was added as a regenerating agent. The flow rate was set as 1ml/minute, temperature as 40˚C, pressure as 8.2 Mpa and the injection volume as 10 µL. The eluents were sonicated for 15 minutes and filtered through 0.45 µm cellulose acetate filters (Sartorius, Ministar) before use, to prevent the entrance of air bubbles and other impurities. For calibration different standards solutions including 0.5, 1, 5, 10, 15, 20 ppm for cations and 0.1, 0.5, 0.7, 1.5 ppm for anions were prepared (John et al., 1997).

2.3. Analysis of heavy metals

Soil sample (0.5 g each) was taken in a glass tube for digestion with HCl and HNO_3 and heated to get the transparent solution. The solution was filtered through Whatman's 0.45 µm filter paper and diluted to 50 ml with distilled water. The concentrations of heavy metals (Cd, Cr, Cu, Mn, Ni, Pb, Zn and Fe) were determined in filtrate of soil samples using atomic absorption spectrophotometer (AAS) (Perkin-Elmer model 700, USA), under standard operating conditions at the Centralized Resource Laboratory, University of Peshawar. Analytical grade chemicals with 99.9% spectroscopic purity (Merck Darmstadt, Germany) were used for sample preparation and analysis. Double distilled water was used throughout the analysis. Standard solutions of all eight elements were prepared by diluting 1000 ppm certified standard solutions (Fluka Kamica, Buchs, Switzerland) of corresponding metal ions. The integration and delay time of AAS was 5 sec. The instrumental detection limits of Cd, Cr, Cu, Mn, Ni, Pb, Zn and Fe were 0.0008, 0.0030, 0.0015, 0.0015, 0.0060, 0.0150, 0.0015 and 0.005 ppm, respectively.

3. Results and discussion

3.1. Chemical characteristics of soil

3.1.1. Cations and anions concentration

The mean concentrations of various cations and anions in the soils collected from different distances from surrounding areas of the storage ponds of the study area are given in Table 1. The concentrations of ions in soil samples collected from southern side of the produced ponds were noticed as Na+ ranged from 4020±3.00 to 7870±5.00 ppm, K+ from 115±2.00 to 255±3.00 ppm. Ca^{+2} ranged from 6727±5.00 to 11122±9.00 ppm and Mg^{+2} ranged from170±1.00 to 234±1.00 ppm. The concentration of Cl^{-} ranged from 5980±5.00 to 6397±3.00 ppm, F^{-} ranged from 0.5±0.01 to 0.88±0.01 ppm, SO_4^{-2} ranged from5.9±0.50 to

11.36±1.20 ppm, NO_3^- ranged from 78±1.00 to 115±1.00 ppm and NO_2^- ranged from 1±0.01 to 3±0.50 ppm.

Similarly, the ions concentrations in the eastern side of the produced water ponds were noted as Na+ ranged from 5690±5.00 to 6714±5.00 ppm, K+ ranged from 211±1.00 to 277±1.00 ppm, Ca^{+2} ranged from 5783±3.00 to 9293±6.00 ppm and Mg^{+2} ranged from 223±1.00 to 280±2.00 ppm. The contents of Cl^- ranged from 4585±5.00 to 5304±5.00 ppm, F^- ranged from 0.37±0.02 to 2.4±0.02 ppm, SO_4^{-2} ranged from 6±0.40 to 15±0.70 ppm, NO_3^- ranged from 179±2.00 to 220±2.00 ppm and NO_2^- ranged from 2.60±0.02 to 4±0.50 ppm.

On western side of the produced water ponds, the concentrations of Na+ ranged from 4130±4.00 to 7100±4.00 ppm, K+ ranged from 243±1.00 to 312±1.00 ppm, Ca^{+2} ranged from 6200±2.00 to 11045±7.00 ppm, Mg^{+2} ranged from 296±1.00 to 3.2±0.20 ppm, Cl^- ranged from 5020±4.00 to 7350±5.00 ppm, F^- ranged from 0.42±0.02 to 3.2±0.01 ppm, SO_4^{-2} ranged from 7.40±0.30 to 18±1.00 ppm, NO_3^- ranged from 311±2.00 to 345±2.00 ppm and NO_2^- ranged from 2.8±0.01 to 5±0.30 ppm.

The results of the soils samples obtained from southern, eastern, and western sides of the produced water ponds of the study area were compared with the reference soil samples in Figure 2. It was found that the concentrations of cation and anions in the soil close to produced water ponds were higher than that of the reference soil as shown in Figure 2. It was also noticed that there was a systematic decrease of cations and anions while moving away from the produced water ponds of the study area. Considering the distribution of various cations and anions in the soil spread around the produced water ponds of the study area and in the soil samples of reference area, it is noticed that the soil samples collected in proximity to the produced water ponds are highly contaminated with the analyzed cations and anions. These kinds of contaminations will certainly have effects on the ecosystem of the area, especially the plant growth in the area.

For different parts of the plant growth, some metals are considered to be of vital importance but if their concentration increase their toxicity is also increased and cause harmful effects on the plants growth. For example, if the amount of Na^+ and Cl^- increases in soil it causes different problems particularly altering the soil chemistry and as a result damaging effects are noticed in the plants. Moreover it further decrease the infiltration and hydraulic conductivity of the soil (Bagarello et al., 2006; Tarchitzky et al., 1999). It also disturbs the movement of water through a soil profile and across the landscape (Coppola et al., 2006).

3.1.2. Heavy metals concentrations

The mean contents of the heavy metals in the soils collected from surroundings of the produced water ponds at different distances in the study area are presented in Table 2. The results shows that heavy metals are present in considerable amount in the soil. This is due to the wide range of chemicals containing heavy metals being discharged into the environment as a result of petroleum exploration and production activities.

It is clear from the Figure 4 that concentration of heavy metals in soils samples at a distance of 0, 30, 60, 90, 120 meter from ponds significantly vary in the southern side of the ponds. Cr concentrations ranged from 4±1.8 to 6.8±2.2 ppm, Mn from 17±3 to 27±6 ppm, Cd from 0.01±0.001 to 0.05±0.001 ppm, Zn from 7±1.5 to 24±3 ppm, Cu from 1.8±.5 to 12±1.8 ppm, Pb from 2.9±0.5 to 19±3 ppm, Ni from 2.2±0.5 to 4.2±1 ppm and Fe from 59±12 to 78±14 ppm.

The concentrations of heavy metals in the eastern sides of the ponds of produced water are continuously decreasing away from the ponds (Fig. 4). Cr ranged from 2.9±1 to 5.1±2.5 ppm, Mn from 18±3 to 30±5 ppm, Cd from 0.01±0.001 to 0.08±0.002 ppm and Zn from 5±1 to 17±2 ppm. Concentration of Cu ranged from 1.5±0.01 to 13±1.3 ppm, Pb from 4.2±0.8 to 16±1.4 ppm, Ni from 3.1±0.5 to 6.2±1 ppm and Fe from 50±8 to 75±12 ppm.

Similarly, there is continuous decrease of heavy metals with increasing distance on the western sides of the ponds. Cr ranged from 3±1 to 4±1.4 ppm, Mn from 14±3 to 41±11 ppm, Cd from 0.01±0.001 to 0.07±0.001 ppm, Zn from 4±0. 6 to 14±1.2 ppm, Cu from 1.8±0.1 to 16±1.6 ppm, Pb from 2.2±0.04 to 3.7±0.7 ppm, Ni from 2.2±0.4 to 4.8±0.7 ppm and Fe from 43±8 to 83±15 ppm.

The concentration of heavy metals of the soils collected from different direction (i.e., southern, eastern and western sides) around produced water ponds were compared with the reference soil. It was found that heavy metals including Cr, Mn, Cd, Pb, Ni and Fe concentrations in all directions from ponds were above the limits of the reference soil as shown in Figure 4. All the heavy metals showed a decreasing trend in concentration with increasing distance from the wastewater ponds. Asia el al., (2007) conducted their research study on Niger delta in order to analyze the impacts of exploration activities on surrounding environment. Their results indicated that the concentrations of Pb, Cu, Ni Cd, Fe, Zn and Cr in the soil were found higher than that of this study. However, Malik et al. (2010) studied the soil samples collected from the areas surrounding industrial city Sialkot, Pakistan and found that the values of Cd, Cr, Cu, Ni, Fe, Pb and Zn were several folds lower than that of the present study.

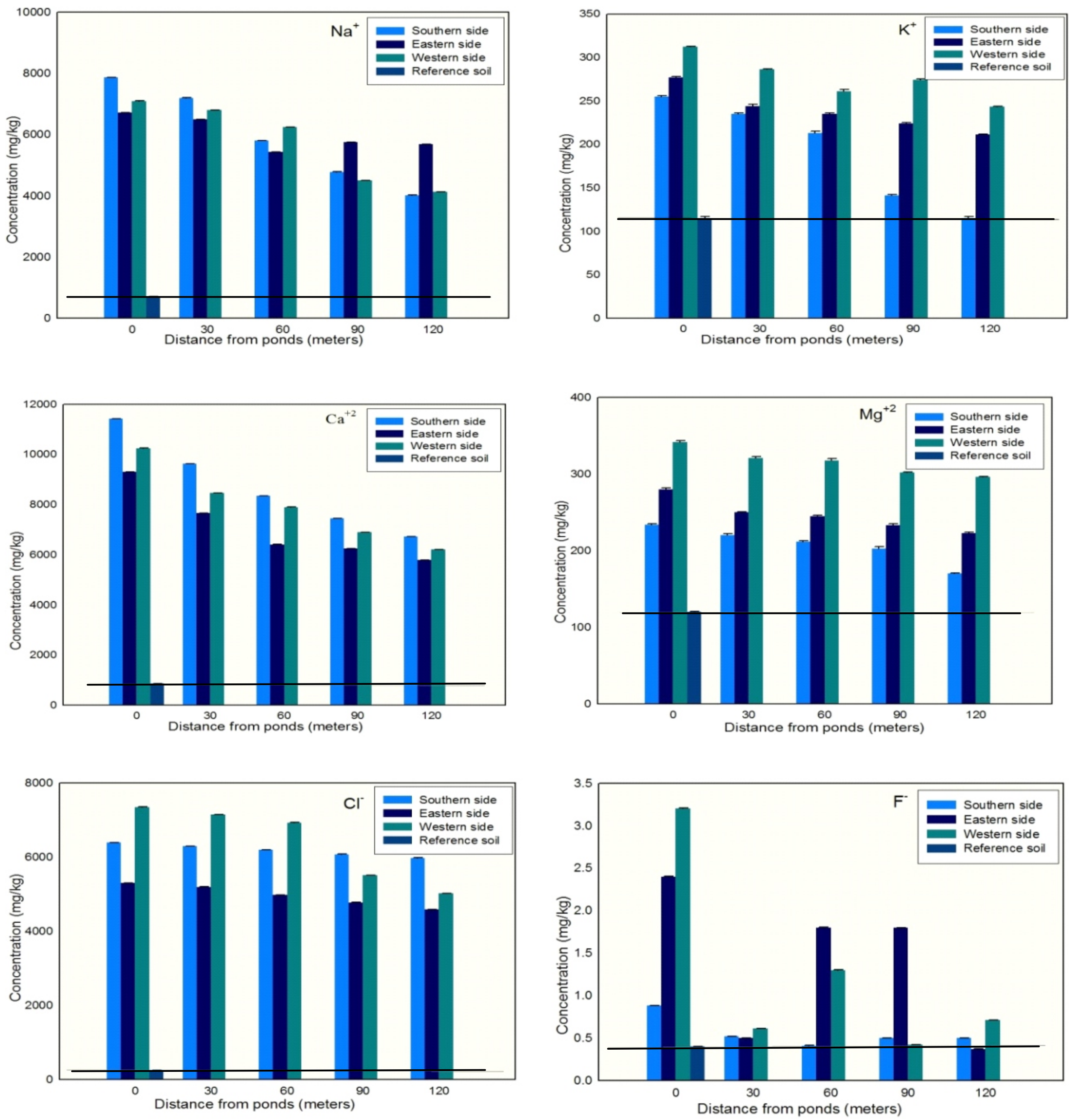

Fig. 2. Mean concentrations of anions and cations in soil samples of the study area; horizontal lines represent concentrations in reference soil.

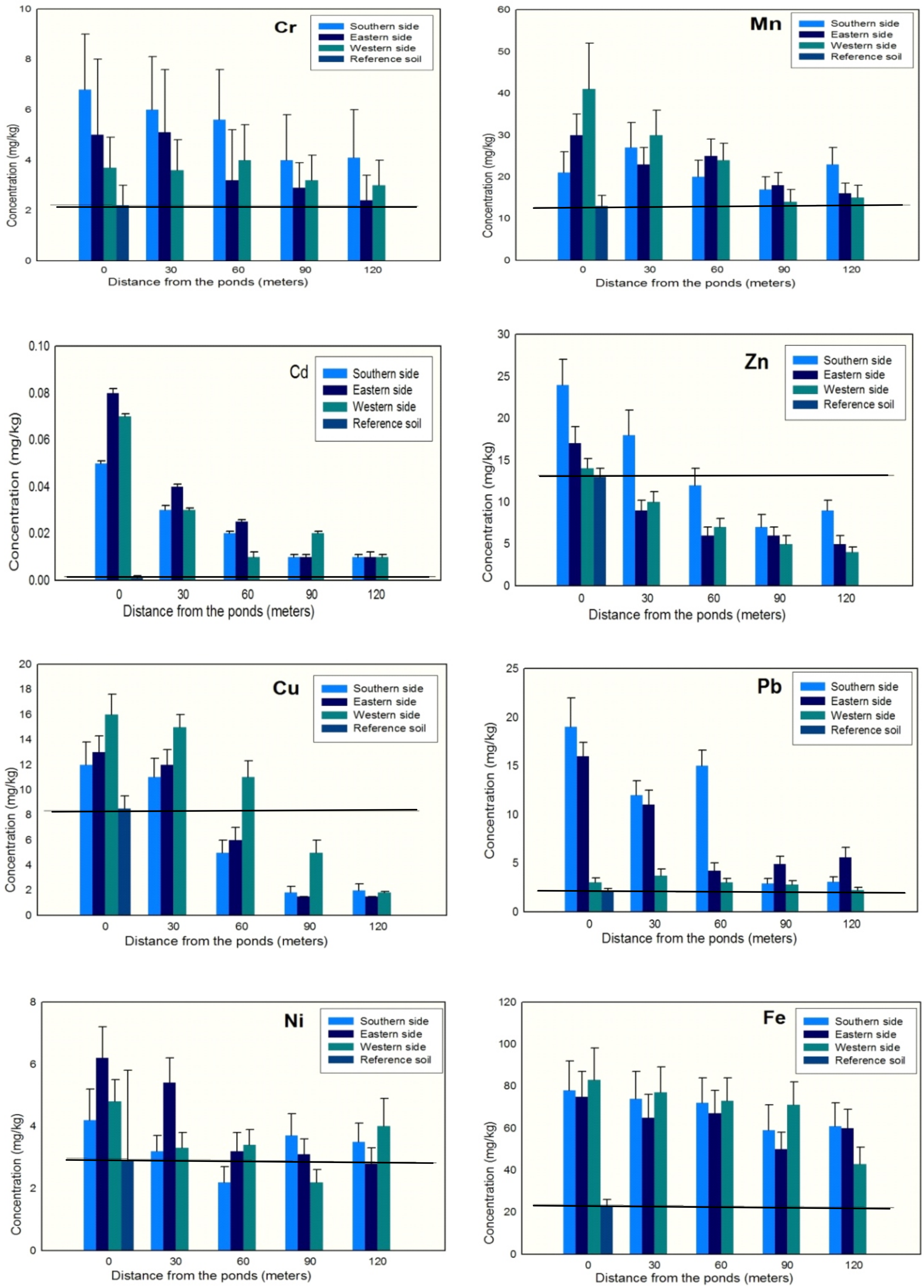

Fig. 4. Mean concentration of heavy metals in soil samples of the study area; horizontal lines represent concentrations in reference soil.

Table 1. Mean concentration of Cations and anions in soil near ponds area, Sadqal oil and gas field Fateh jang, Punjab Pakistan.

Sampling Area	Depth (cm)	Distance	Concentration (ppm)								
			Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	F^-	SO_4^{-2}	NO_3^-	NO_2^-
Southern side	0-20	0-Meter	7870±5.00	255±3.000	11122±9.00	234±1.00	6397±5.00	0.88±0.01	11 ±1.20	115±1.00	3±0.50
		30-M	7200±3.00	235±1.00	9623±3.00	220±2.00	6289±5.00	0.52±0.02	6.9±0.50	118±2.00	2±0.10
		60-M	5800±2.00	213±2.00	8345±4.00	212±1.00	6191±4.00	0.41±0.01	5.9±0.50	105±1.00	1.5±0.05
		90-M	4780±2.00	141±1.00	7453±3.00	203±2.00	6075±4.00	0.5±0.01	7.4±0.80	95±2.00	1±0.01
		120-M	4020±3.00	115±2.00	6727±5.00	170±1.00	5980±5.00	0.5±0.01	7.7±0.50	78±1.00	1.6±0.04
Eastern side	0-20	0-Meter	6714±3.00	277±1.00	9293±6.00	280±2.00	5304±5.00	2.4±0.02	15±0.70	220±2.00	4±0.50
		30-M	6500±2.70	244±2.00	7654±1.00	250±1.00	5194±5.00	0.5±0.01	6±0.40	212±3.00	2.6±0.02
		60-M	5428±4.00	235±1.00	6402±3.00	245±1.00	4980±5.00	1.8±0.02	8.8±0.50	215±1.00	2.9±0.10
		90-M	5750±3.00	224±1.00	6237±2.00	233±2.00	4773±4.00	1.8±0.01	8.6±0.80	201±2.00	3±0.20
		120-M	5690±5.00	211±1.00	5783±3.00	223±1.00	4585±5.00	0.37±0.02	8.4±0.50	179±2.00	2.8±0.50
Western side	0-20	0-Meter	7100±4.00	312±1.00	11045±7.00	342±2.00	7350±5.00	3.2±0.10	18±1.00	345±2.00	5±0.30
		30-M	6800±4.00	286±2.00	8454±5.00	321±2.00	7145±4.00	0.61±0.02	7.8±0.50	326±1.00	3±0.20
		60-M	6245±3.00	261±1.00	7894±2.00	318±2.00	6930±5.00	1.3±0.01	9.1±0.50	311±2.00	3.4±0.10
		90-M	4500±3.00	274±1.00	6890±3.00	302±1.00	5505±3.00	0.42±0.02	7.5±0.50	315±3.00	2.8±0.01
		120-M	4130±4.00	243±1.00	6200±2.00	296±1.00	5020±4.00	0.71±0.01	7.4±0.30	316±2.00	3.2±0.05
Reference Soil	0-20	5 km	700±3.00	115±2.00	850±1.00	120±1.00	250±3.00	0.4±0.01	2.7±0.20	90±1.00	1.8±0.05

Table 2. Mean concentration of heavy metals in soil near ponds area, Sadqal oil and gas field Fateh jang, Punjab Pakistan.

Sampling Area	Depth (cm)	Concentration (ppm)								
		Distance	Cr	Mn	Cd	Zn	Cu	Pb	Ni	Fe
Southern side	0-20	0-Meter	6.8±2.200	21±5. 000	0.05±0.001	24±3.000	12±1.800	19±3.000	4.2±1.000	78±14.000
		30-M	6±2.100	27±6. 000	0.03±0.002	18±3.000	11±1.500	12±1.500	3.2±0.500	74±13.000
		60-M	5.6±2. 000	20±4.000	0.02±0.001	12±2.000	5±1.000	15±1.600	2.2±0.500	72±12.000
		90-M	4±1.800	17±3.000	0.01±0.001	7±1.500	1.8±0.500	2.9±0.500	3.7±0.700	59±12.000
		120-M	4.1±1.900	23±4.000	0.01±0.001	9±1.200	2±0.500	3.1±0.500	3.5±0.600	61±11.000
Eastern side	0-20	0-Meter	5±3.000	30±5.000	0.08±0.002	17±2.000	13±1.300	16±1.400	6.2±1.000	75±12.000
		30-M	5.1±2.500	23±4.000	0.04±0.001	9±1.200	12±1.200	11±1.500	5.4±0.800	65±11.000
		60-M	3.2±2.000	25±4.000	0.025±0.001	6±1.000	6±1.000	4.2±0.800	3.2±0.600	67±11.000
		90-M	2.9±1.000	18±3.000	0.01±0.001	5±1.000	1.5±0.010	4.9±0.800	3.1±0.500	50±8.000
		120-M	2.4±1.000	16±2.000	0.01±0.002	5±1.000	1.5±0.010	5.6±1.000	2.8±0.500	60±9.000
Western side	0-20	0-Meter	3.7±1.200	41±11.000	0.07±0.001	14±1.200	16±1.600	3±0.500	4.8±0.700	83±15.000
		30-M	3.6±1.200	30±6.000	0.03±0.001	10±1.200	15±1.000	3.7±0.700	3.3±0.500	77±12.000
		60-M	4±1.400	24±4.000	0.01±0.002	7±1.000	11±1.300	3±0.400	3.4±0.500	73±11.000
		90-M	3.2±1.000	14±3.000	0.02±0.001	5±1.000	5±1.000	2.8±0.400	2.2±0.400	71±11.000
		120-M	3±1.000	15±3.000	0.01±0.001	4±0.600	1.8±0.100	2.2±0.300	4±0.900	43±8.000
Reference Soil	0-20	5 km	2.2±0.800	13±2.500	0.001±0.001	13±1.000	8.5±1.000	2.1±0.300	2.9±0.800	23±3.000

When depositions of heavy metals such as Cd, Zn, Cr, Ni, Pb and Mn on the surface of soil increases its capacity of holding heavy metals decreases. As a result, the heavy metals are released into the groundwater and hence contaminating the groundwater. This is ultimately resulted in the health risk for the inhabitants of the area. This is the reason that excessive accumulation of heavy metals in agricultural soils may not only result in soil contamination (Zhao et al., 2010), but also leads to elevated heavy metals uptake by crops (Muchuweti et al., 2006) which may impact the food chain (Murtaza et al., 2010). Excessive uptake of heavy metals by plants is neither good for plants nor for human beings. They cause phytotoxicity in plants and health problems in human (Haq et al., 2003). Heavy metals in the human bodies can cause serious health problems. Metals specially Mg, Ni and As can cause tachycardia, increased blood pressure and anemia which is due to inhibitory effect on hematopoiesis (Huang and Ghio, 2006). Cd, Cr, Ni and Pb are very toxic pollutants, their excessive bioaccumulation through food chain can cause biochemical changes both chronic and acute health consequences, including kidney dysfunction, polycythemia, bone fracture, respiratory illness, memory deterioration, asthma, heart problems and various kind of cancers (Fischer et al., 2003; Khan et al., 2010; Cigdem et al., 2013). The presence of micro organisms in soil is very important for many practice like assimilation, nitrogen fixation and degradation of organic matter for the use of plants which can be adversely affected by heavy metals in soil (Stuczynskiel et al., 2003; Nwuche and Ugodi, 2008). The heavy metals accumulation in the areas premises to the storage ponds of produced water (waste water) could be very effective in causing environmental degradation. Therefore, the inhabitants of the area of study should be educated regarding the long term environmental impact on the health of human being and also on the growth of plants.

4. Conclusions

The studied cations (i.e., Na^{+} , K^{+} , Ca^{+2}, Mg^{+2}), anions (i.e., Cl^{-}, F^{-}, SO_4^{-}, NO_3^{-}) and heavy metals (i.e., Cr, Mn, Cd, Zn, Cu, Pb, Ni, Fe) in the soils surrounding the ponds of produced water were found in high concentration as compared to the reference soils. This is indicative of the fact that the waste water of the ponds play a vitol role in contaminating the spoils of the area. This suggests that the oil and gas exploration activity in the region where the produced water (waste water) has greater impact on the soils surrounding the produced water ponds where the waste water is continuously stored and released for many years. Soil is not only a medium for plants to grow or a place to dispose of unwanted constituents, but also contribute many pollutants to surface water, groundwater, atmosphere and food. This is the reason that the pollutants accumulated in the surface soils can be transported to different environmental components. To overcome this problem, there is a strong need to treat wastewater at the source so that the impacts of the storage ponds can be minimized in the study area.

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