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Physico-chemical Properties of Various Types of Wastewaters Used as Source of Irrigation

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ABSTRACT

Wastewater is widely used for irrigation of agricultural lands due to scarcity of freshwater, its reliable supply and high nutrients value. However, untreated wastewater is mostly contaminated with organic pollutants and toxic heavy metals including: cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), copper (Cu), nickel (Ni), zinc(Zn), cobalt (Co), Iron (Fe), molybdenum (Mo) and boron (B). Therefore, chemical analyses of wastewater is of great concern for safe agricultural irrigation. A study was conducted at Central Analytical Facility Division (CAFD) of Pakistan Institute of Nuclear Science and Technology (PINSTECH), Islamabad with the objective to collect various types of wastewater and analyze for their nutrient composition (macro & micronutrients), heavy metals content (As, Hg, Cr, Cd, Pb, Ni) and other physicochemical characteristics including: pH, electrical conductivity (EC), total dissolved solids(TDS), total suspended solids(TSS), chemical oxygen demand (COD) and biological oxygen demand (BOD). Three categories of wastewater including sewage water, industrial wastewater and domestic wastewater being used as irrigation source were collected from various places and were analyzed using atomic absorption spectrometry (AAS) and inductively coupled plasma- optical emission spectrometry (ICP-OES). The obtained results revealed that domestic wastewater (Shah Town, Islamabad) and industrial wastewater (Hayatabad, Peshawar) were found environmentally safe. It was found that sewage water collected from Tarlai farms, Islamabad had no toxic heavy metals except mercury (2.67 ng mL^{-1}) which was slightly above than FAO safe limits. However, sewage water collected from Sohan village, Islamabad is not recommended for irrigation due to its high mercury content (342.14 ng mL^{-1}).

Keywords: *Industrial Wastewater, Domestic Wastewater, Sewage Water, Heavy Metals*

1. Introduction

Wastewater is widely used for irrigation of agricultural lands in developed countries as well as in underdeveloped countries like Pakistan [1]. Almost 20 million hectares of agricultural land is irrigated by wastewater around the globe which is almost 10% of irrigated agrarian land [2]. Droughts, climate change and urban development have put a substantial pressure on freshwater supplies [3]. It is assessed that during next 50 years, more than 40% of the world's population will face water scarcity problem [4]. Pakistan is also facing water scarcity problem as freshwater supply is decreasing gradually. Water scarcity will have significant impacts on agriculture by reducing crop productivity [5] and it will pose serious challenges to food security [6].

Wastewater is produced by different sources such as domestic discharges, industrial effluents, water received from commercial areas, hospitals and urban runoff [7]. Annually 962,335 million gallons of wastewater is generated in Pakistan where 288,326 million gallons receive from industrial discharge and 674,009 million gallons of water from municipal use [8].

Due to shortage of freshwater and high nutrients in waste water has increased its utilization for irrigation purposes [9]. Reusing wastewater for irrigation reduces the need for artificial fertilizers, increases crop yields and helps conserve natural water resources [10]. The nutrient content in the wastewater may exceed the desired level which may damage the crop [11]. Several contaminants such as pathogens, organic pollutants and non-biodegradable toxic heavy metals including Cd, Cr, Hg, Pb, Cu, Ni, Zn, Co, Fe and Mo, are present in untreated wastewater [12]. Hence, consistent use of untreated wastewater for irrigation may cause heavy metal accumulation in agricultural soil [13]. These harmful pollutants can be absorbed by plants, which can then enter in the food chain, posing a serious health risk [14]. Consumption of contaminated food may result in serious health problems in humans such as growth retardation, gastro intestinal cancer and kidney and liver malfunctions [15]. Therefore, assessing chemical quality of wastewater is of great concern for safe agricultural irrigation [16]. The, wastewater must be analyzed for its toxicity and other physico-chemical characteristics prior using for irrigation purposes.

2. Materials

The study was conducted during 2018 to 2019 at the Central Analytical Facility Division (CAFD), PINSTECH, Nilore, Islamabad. The study was carried out with the objective to analyze physicochemical characteristics of different categories of wastewater used as source of irrigation.

2.1 *Wastewater collection*

Composite samples of wastewater (sewage water, industrial wastewater, domestic wastewater) used for irrigation of agricultural fields and vegetable farms were collected from four different sites as shown in Table 1.

Table 1: Wastewaters samples collected from various sites.

Type of wastewater	Collection Date	Collection Site
Industrial waste water Site 2 & Site 7	March 20, 2019	Hayatabad Industrial Estate (HIE), Peshawar
Domestic Waste Water	Jun 12, 2019	Shah Town, Sohan Islamabad
Sewage water	Jun 12, 2019	Sohan Village, Islamabad
Sewage Water	Jun 12, 2019	Tarlai Farms, Islamabad

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Industrial wastewater samples were collected from two different sites in Hayatabad Industrial Estate (HIE), Peshawar. The estate discharges effluents into Kabul River which is main irrigating canal of Peshawar. Match factories, paint factories and pharmaceutical industries discharge their effluents in these sites. Site 2 was located 10 meters away from the main drain while Site 7 was 100 meters away. Sewage water samples were collected from Sohan, Islamabad (33°39'44.7"N 73°06'06.7"E) and P&V Farms, Tarlai, Islamabad (33°38'40.4"N 73°08'15.0"E) whereas domestic wastewater was collected from Shah town, Sohan, Islamabad. The wastewater samples were collected below 10 cm of water surface to avoid floating particles and were preserved in pre cleaned plastic bottles. Non-powdered gloves and face mask were worn during samples collection. After proper labeling, the samples were safely transported to the Atomic Absorption lab at CAFD, PINSTECH Nilore, Islamabad. The samples were kept in the refrigerator to inhibit any microbial activity in the samples.

2.2 Chemical analysis

The waste water samples were analyzed using Inductively Coupled Plasma Optical Emission Spectrometry for macro and micro nutrients determination while Atomic Absorption Spectrophotometer (AAS) for heavy metals analysis. The analytical procedures and respective instruments used for physico-chemical analysis of organic wastes are described in Table 2.

Table 2: List of parameters and instruments used for physico-chemical analysis of wastewater.

Parameters	Instruments/Model
Heavy Metals	
(Pb, Cd	GFAAS, Hitachi Z-8000
As, Hg, Se, Sb)	HGAAS, GBC-932plus
Macro-nutrients	
(Na, Ca, Mg, P, K)	ICP-OES, Thermo, iCAP-6500
Micro-nutrients	
(Cu, Mn, Zn, Cu, Fe)	ICP-OES, Thermo, iCAP-6500
Physico-chemical Parameters	
pH	pH meter, Oakton pH 2100 series
Conductivity, TDS	Conductivity meter, InoLab
TSS, Ammonia	Photometer, MultidirectLovibond
Sulphide, Fluoride, Nitrate Chloride, COD	Photometer, Spectrodirect RS-232
BOD	DO meter

2.3 Heavy metal analysis

Heavy metal analysis of wastewater samples was performed using atomic absorption spectrometry. Graphite Furnace AAS (Hitachi Z-8000) was used for Pb and Cd analysis while Hydride Generation Spectrophotometer (GBC-932plus) was used for determination of As, Se, Sb and Hg in samples. Some macronutrient (N, P, K, Mg, Na, Ca) and micronutrients (Fe, Cu, Zn) were determined by using (ICP-OES), Thermo, iCAP-6500.

3. Results and Discussion

According to an estimate, up to one-tenth of the population of the world consumes food produced by using wastewater as irrigation source [12]. Farmers use wastewater for irrigation because of its nutrient content and reliable supply. In Pakistan, various types of wastewater are being used as a source of irrigation. In this study, three types of wastewater i.e., sewage water, industrial wastewater and domestic wastewater were analyzed for various physico-chemical parameters and elemental profile.

3.1 Sewage water

Sewage water is being used for irrigating the vegetables, as it contains several macro-nutrients and micro-nutrients. In this study, sewage water was collected from Tarlai Farms, Islamabad and Sohan, Islamabad and analyzed for its physico-chemical chemical characterization.

The quality of sewage water was evaluated with respect to its nutrient composition, heavy metals and for its various other physico-chemical parameters. The results are given in Table 3 and Table 4.

3.1.1 Tarlai farms

The results showed that sewage water had pH 7.6 and electrical conductivity of 1.12 dS m^{-1}. Total dissolved solids (TDS) is an important parameter which indicates the presence of inorganic salts in the form of cations and anions [17]. The results showed that TDS value was 614 mg L^{-1} which is below the safe limit. The results further revealed that ammonia (0.12 mg L^{-1}), fluoride (0.60 mg L^{-1}), chloride (16.26 mg L^{-1}), alkalinity (516 mg L^{-1}) and sulphate (31.75 mg L^{-1}) in sewage water were in the permissible limit as described by WHO, 2006 [18].

Table 3: Physicochemical properties of the sewage water (Tarlai Farms and Sohan, Islamabad) with safe limits [18]

Parameters	Units	*Tarlai Farms*	*Sohan Village*	Safe Limits
pH	-	7.6	7.3	6.5-8.4
Conductivity	dS m^{-1}	1.12	0.65	0.25-3.00
TDS	mg L^{-1}	614	355	<2000
TSS	mg L^{-1}	24	7	50-100
Ammonia	mg L^{-1}	0.12	4.13	5
Alkalinity	mg L^{-1}	516	209	<610
Sulfide	mg L^{-1}	ND	ND	
Fluoride	mg L^{-1}	0.60	0.45	1.0
Chloride	mg L^{-1}	16.26	15.79	<350
Sulphate	mg L^{-1}	31.75 ± 0.17	39.77 ± 0.15	500
Nitrate	mg L^{-1}	ND	ND	
COD	mg L^{-1}	23	520	250
BOD	mg L^{-1}	36	42	

However, sulphide was not detected in the sample. Another important parameter i.e., COD (Chemical Oxygen Demand) is useful which indirectly measures the number of organic compounds in water The COD value was found to be 23 mg L^{-1} which is within permissible limits proposed by WHO.

The analyses of sewage water performed using ICP-OES showed that sewage water contains macronutrients including calcium (69.43 µg mL^{-1}), potassium (16.37 µg mL^{-1}), magnesium (28.24 µg mL^{-1}), phosphorus (1.63 µg mL^{-1}) and sodium (84.77 µg mL^{-1}) as shown in Table 3.2. Potassium content is higher than 2 µg mL^{-1} which is the value recommended by FAO [19]. Among micronutrients, only Zn (10 ng mL^{-1}) was detected in the water sample while other micronutrients such as Cu, Fe, Mn were not detected in the sample.

Toxic metals concentration analysis showed that Pb, Cd, Sb, Hg, Se, Cr, Ni were not detected in the sewage water. Although As (5.64 ng mL^{-1}) was found in the sample but it was well below the safe limits proposed by WHO 2006 [18]. However, Hg (2.67 µg mL^{-1}) was a little (0.67 ng mL^{-1}) higher than the safe limit.

Table 4: Elemental profile of sewage water (Tarlai Farms and Sohan, Islamabad) with safe limits.

Elements	Unit	*Tarlai Farms*	*Sohan*	Safe Limits
Ca	µg mL^{-1}	69.43 ± 1.38	73.88 ± 1.19	230
K	µg mL^{-1}	16.37 ± 0.11	9.14 ± 0.03	<2.0
Mg	µg mL^{-1}	28.24 ± 0.38	14.69 ± 0.18	< 61
P	µg mL^{-1}	1.63 ± 0.02	1.55 ± 0.01	
Na	µg mL^{-1}	84.77 ± 1.6	32.78 ± 0.5	230
Fe	µg mL^{-1}	ND	0.02 ± 0.00	0.1-1.5
Mn	µg mL^{-1}	ND	ND	0.1-1.5
Cu	µg mL^{-1}	ND	ND	200
Zn	ng mL^{-1}	10	10	2000
Ni	µg mL^{-1}	ND	ND	0.20
Cr	µg mL^{-1}	ND	ND	100
As	ng mL^{-1}	5.64 ± 0.33	ND	100
Cd	ng mL^{-1}	ND	ND	10
Pb	ng mL^{-1}	ND	ND	5000
Se	ng mL^{-1}	ND	ND	20
Sb	ng mL^{-1}	ND	ND	
Hg	ng mL^{-1}	2.67 ± 0.02	342.14 ± 0.62	2

Sewage water from Tarlai Farm, Islamabad was also analyzed by M. Zeeshan et al. [20]. The reported results are close to results of this study including ammonia (0.03-0.46 mg L^{-1}), fluoride (0.5-0.95 mg L^{-1}) and chloride (4.7- 24.1 mg L^{-1}).

However, elemental profile of the two studies is quite different such as Hg was not detected by Zeeshan et al [20] while in our study Hg is above the safe limit (2.67 mL^{-1}), As, Ca and K reported by Zeeshan were 2.17 ng mL^{-1} , 34.38 µg mL^{-1} and 6.32 µg mL^{-1} respectively which are different from the results of this study.

3.1.2 Sohan village Islamabad

The physicochemical properties of sewage water samples collected from Sohan village, Islamabad are given in Table 4.

The results showed that sewage water had a pH of 7.3 and an electrical conductivity of 0.65 dS m^{-1} which falls in safe limit. The results showed that TDS value was 355 mg L^{-1} which is below the safe limit. The results further revealed that sulfide, fluoride, chloride, alkalinity ammonia and sulphate in sewage water (Sohan Village) were in the permissible limit as described by WHO, 2006[18]. COD parameter indirectly measures the number of organic compounds in water. The analyses showed that COD (520 mg L^{-1}) was higher than the safe limit which indicates that a high quantity of organic contaminants is present in the sewage water samples [21]. However, BOD was below the safe limit.

The macro-nutrients for Ca, K, Mg, P and Na were found 73.88 µg mL^{-1}, 9.14 µg mL^{-1}, 14.69 µg mL^{-1},1.55 µgmL^{-1} and 32.78 µg mL^{-1} respectively as shown in Table 4. Among micronutrients Fe (0.02 µg mL^{-1}) and Zn (10 ng mL^{-1}) were detected in the water sample while other micronutrients such as Cu and Mn were absent in the samples.

The toxic heavy metal profile of sewage water samples showed that Pb, Cd, As, Cr, Ni, Se, Sb were not detected in the sewage water. However, Hg (342.14 ng mL^{-1}) was much higher (171 times) than the safe limit proposed by WHO [18]. The higher level of Hg in water sample can be attributed to the disposal of hospital wastes in the water. Hospital wastes contained many mercury sources like thermometer, teeth fillers etc. Due to presence of higher Hg content and its ability to bio accumulate this water is not suitable for agricultural use to avoid contamination of food chain. Since Hg is highly toxic and can accumulate in human body causing severe neurological disorders and effects fetal development if mother is exposed to mercury [22].

3.2 Industrial wastewater

In developing countries, effluents from industrial areas have been used as source of irrigation because these effluents are considered as nutrient-rich irrigation source [23]. Industrial wastewater was obtained from Site 2 and Site 7 in Hayatabad Industrial Estate (HIE), Peshawar which is being used as a source of irrigation of crops and vegetable farm. The effluents from match factories, pharmaceutical industries and paint industries were discharged at these sites. Site 7 was 10 meters away from the main drainage while Site 2 was 100 meters away.

3.2.1 Site 2, Peshawar

The quality of industrial wastewater was evaluated with respect to heavy metals content, macronutrients and for its various other physicochemical properties and the results are shown in Table 5 and 6.

Table 5: Physico-Chemical parameters of industrial wastewater (Site 2 and Site 7 Hayatabad, Peshawar)

Parameters	Units	*Site 2*	*Site 7*	Safe Limits
pH		7.8	8.2	6.5-8.4
Conductivity	dS m^{-1}	0.82	0.93	0.25-3.00
TDS	mg L^{-1}	449	511	<2000
TSS	mg L^{-1}	57	6	50-100
Ammonia	mg L^{-1}	8.6	0.23	5
Alkalinity	mg L^{-1}	-	216	<610
Sulphide	mg L^{-1}	ND	ND	
Fluoride	mg L^{-1}	0.78	0.62	1.0
Chloride	mg L^{-1}	5.08	51.58	<350
Sulphate	mg L^{-1}	110.46 ± 1.35	238.73 ± 0.53	500
Nitrate	mg L^{-1}	11.25	9.62	
COD	mg L^{-1}	40	400	250

The results showed that wastewater had pH 7.8 and electrical conductivity of 0.82 dS m^{-1}. Electrical conductivity value showed that water contained ionic species. The results showed that TDS and TSS value in wastewater were 449 mg L^{-1} and 57 mg L^{-1} (Table 5). TSS value was above the safe limits which indicate the presence of solid pollutants.

The results further revealed that COD, sulfide, fluoride, chloride and sulphate in sewage water were in the permissible limit as described by WHO, 2006 [18] as shown in Table 5. The COD value of wastewater was 40 mg L^{-1} which is below the safe limit proposed by WHO [18].

The analyses of wastewater performed using ICP-OES showed that wastewater contained macronutrients including P (2.11 µg mL^{-1}), Na (51.77 µg mL^{-1}), Ca (55.96 µg mL^{-1}), K (3.58 µg mL^{-1}) and Mg (31.15 µg mL^{-1}) as shown in Table 6. Except for K, all macro-nutrients were within the permissible limits. Among micronutrients, results showed that water contained Fe (0.03 µg mL^{-1}) and Zn (1.16 µg mL^{-1}) while Cu and Mn were not detected in the sample.

Heavy metal analysis of wastewater showed that Hg, Pb, Cd, As, Cr, Ni and Se were not detected in the industrial wastewater. As and Sb were found (4.39 ng mL^{-1}) and (2.07 ng mL^{-1}) respectively but these were below the safe limits proposed by WHO [18].

3.2.2 Site 7, Peshawar

The elemental profile and results of various other physico-chemical parameters are shown in Table 5 and Table 6. The physicochemical properties of industrial water samples are given in Table 5. The results showed that sewage water had pH in alkaline range (8.2) and electrical conductivity of 0.93 dS m^{-1}. The results showed that TDS (511 mg L^{-1}), TSS (6 mg L^{-1}) and alkalinity (216 mg L^{-1}) in wastewater were below the safe limit. The results further revealed that sulfide, fluoride, chloride and sulphate in sewage water were in the permissible limit as described by WHO, 2006 [18]. COD value 0f 400 mg L^{-1} is indicating organic load.

The macro-nutrients analysis of wastewater showed that all macronutrients (Ca, Mg, Na, P, K, Na) were within permissible limits except Potassium as shown in Table 6. The upper limit for K proposed by WHO is 2µg mL-1 measured value for K was 4.28 µg mL-1. Plants need P for development of ATP, nucleic acids and sugars. Plants suffering from P deficiency appear weak and maturity is delayed. Hence, this source of water used as a source of irrigation will affect plant growth. The results showed that none of the micro-nutrients was present in the sample which would affect plant growth parameters.

Table 6: Elemental Profile of industrial wastewater (Site 2 and Site 7 Hayatabad, Peshawar.

Elements	Unit	Site 2	Site 7	Safe Limits
Ca	µg mL^{-1}	55.96 ± 3.15	111.11 ± 3.3	230
K	µg mL^{-1}	3.58 ± 0.13	4.28 ± 0.11	<2.0
Mg	µg mL^{-1}	31.15 ± 0.70	29.94 ± 0.06	< 61
P	µg mL^{-1}	2.11 ± 0.06	0.09 ± 0.00	
Na	µg mL^{-1}	51.77 ± 2.69	34.89 ± 0.90	230
Fe	µg mL^{-1}	0.03 ± 0.00	ND	0.1-1.5
Mn	µg mL^{-1}	0.03 ± 0.00	ND	0.1-1.5
Cu	µg mL^{-1}	ND	ND	200
Zn	µg mL^{-1}	± 0.05	ND	2
Ni	µg mL^{-1}	ND	ND	0.20
Cr	µg mL^{-1}	ND	ND	100
As	ng mL^{-1}	4.39 ± 0.12	ND	100
Cd	ng mL^{-1}	ND	ND	10
Pb	ng mL^{-1}	ND	ND	5000
Se	ng mL^{-1}	ND	1.57 ± 0.03	20
Sb	ng mL^{-1}	2.07 ± 0.03	2.59 ± 0.07	
Hg	ng mL^{-1}	ND	ND	2

Among toxic heavy metals Pb, Cd, As, Hg, Ni and Cr were not detected in the wastewater. Although Sb (2.59 ng mL^{-1}) and Se (1.57 ng mL^{-1}) were detected in the sample but they were well below the safe limits proposed by WHO 2006 [18].

3.3. Domestic wastewater

Domestic wastewater was collected from a residential colony located in Sohan, Islamabad. The quality of domestic wastewater used as a source of irrigation to vegetables was analyzed for macro and micro-nutrients, heavy metals content and other parameters.

3.3.1 Shah town, Islamabad

Analysis of domestic wastewater was performed at laboratories at CAFD, PINSTECH. The results are mentioned in Table 7 and 8.

The domestic wastewater had a pH of 7.3 and an EC of 1.05 dS m^{-1}. The results showed that TDS (581 mg L^{-1}), TSS (27 mg L^{-1}) and alkalinity (240 mg L^{-1}) in wastewater were below the safe limit. The results further revealed that COD, sulfide, fluoride, chloride and sulphate in sewage water were in the permissible limit as described by FAO, 1985 [16].

Table 7*:* Physico-chemical characteristics of domestic wastewater (Shah Town, Islamabad).

Parameters	Units	Value	Safe Limits
pH	-	7.3	6.5-8.4
Conductivity	dS m^{-1}	0.11	0.25-3.00
TDS	mg L^{-1}	581	<2000
TSS	mg L^{-1}	27	≤50
Ammonia	mg L^{-1}	2.3	5
Alkalinity	mg L^{-1}	240	<610
Sulfide	mg L^{-1}	ND	
Fluoride	mg L^{-1}	0.79	1.0
Chloride	mg L^{-1}	42.72	<350
Sulphate	mg L^{-1}	45.32 ± 0.29	500
Nitrate	mg L^{-1}	ND	
COD	mg L^{-1}	220	250

The analyses of domestic wastewater performed on ICP-OES showed that it contained macronutrients including P(4.10 µg mL^{-1}), Na (60.01 µg mL^{-1}), Ca (81.52 µg mL^{-1}), K (21.29 µg mL^{-1}) and Mg (21.46 µg mL^{-1}) as shown in Table 8. K content is much higher than the recommended value of 2 µg mL^{-1} among micronutrients results showed that water contains Fe (0.03 µg mL^{-1}), Mn (0.12 µg mL^{-1}) and Zn (0.03 µg mL^{-1}) while Cu was not detected in the sample.

The elemental profile of domestic wastewater samples showed that none of the toxic heavy metals such as Hg, As, Pb, Cd, As, Ni, Cr, Sb and Se were detected in the domestic wastewater.

Table 8: Elemental profile of domestic wastewater used for irrigation at Shah Town, Islamabad.

Elements	Unit	Concentration	Safe Limits
Ca	µg mL^{-1}	81.52 ± 3.5	230
K	µg mL^{-1}	21.29 ± 0.56	<2.0
Mg	µg mL^{-1}	21.46 ± 0.45	< 61
P	µg mL^{-1}	4.10 ± 0.08	
Na	µg mL^{-1}	60.01 ± 2.59	230
Fe	µg mL^{-1}	0.03 ± 0.00	0.1-1.5
Mn	µg mL^{-1}	0.12 ± 0.01	0.1-1.5
Cu	µg mL^{-1}	ND	200
Zn	µg mL^{-1}	0.03 ± 0.00	2
Ni	µg mL^{-1}	ND	0.20
Cr	µg mL^{-1}	ND	100
As	ng mL^{-1}	ND	100
Cd	ng mL^{-1}	ND	10
Pb	ng mL^{-1}	ND	5000
Se	ng mL^{-1}	ND	20
Sb	ng mL^{-1}	ND	
Hg	ng mL^{-1}	ND	2

4. Conclusion

Among wastewater as irrigation source, domestic wastewater (Shah Town, Islamabad) is safe for irrigation as it contains no toxic heavy metals as presented in Fig. 1. Industrial wastewater Hayatabad, Peshawar was also found environmentally safe according to WHO limits. It was found that sewage water (Sohan Village, Islamabad) is highly harmful for irrigation due to very high Hg content (342.14 ng mL^{-1}). It is recommended that proper wastewater treatment system shall be introduced for removing toxic heavy metals content prior using for irrigation purposes.

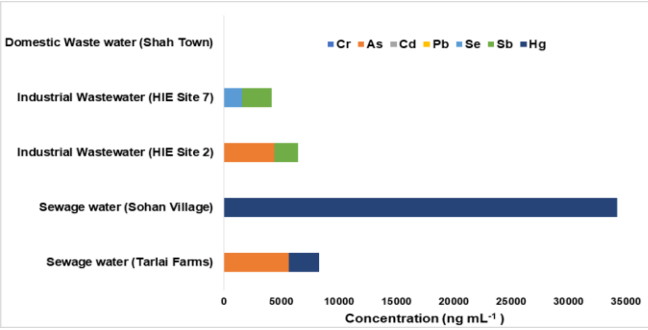

Fig. 1. Heavy Metal Profile of Wastewater Samples.

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