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Environmental Implications of an Industrial Estate in Conjuction with DPSIR Framework

Asma Shahzad[a], Rana Amjad[b]* and Almas Hamid[a]
[a]Department of Environmental Sciences, Kinnaird College for Women, Lahore, Pakistan
[b]Department of Chemistry, Government College Township, Lahore, Pakistan

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Abstract. The aim of this study was to analyze heavy metal levels in effluents of Quaid-e-Azam industrial estate (QIE) and nearby ground water of residential township area. The heavy metal pollution index (HPI) of ground water was also calculated to evaluate health risk. Effluents from the drain mouths of selected industries at QIE were analyzed for arsenic (As), chromium (Cr) and lead (Pb) by employing inductively coupled plasma optical emission spectrometry (ICP-OES). The groundwater was tested for lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), zinc (Zn) and copper (Cu) using atomic absorption spectroscopy (AAS). The heavy metal contamination of both analyses exceeded the national environmental quality standards of Pakistan (NEQs). The HPI of the groundwater of township sector A2 block 2 was 34 whereas that of block 5 was 81 due to its greater proximity to QIE. Microbiological evaluation was also carried out in both of the areas and ground water was tested for coliforms (cfu) and *E. coli* (cfu) including a health survey. Driver-pressure-dtate-impact-response (DPSIR) model was also applied soon after to identify and address environmental issues at QIE. Consequently, sustainability can be achieved if industries adhere to the guidelines strictly in combination with the treatment plant installations and work on devising strategies to reduce the level of pollution.

Keywords: driver-pressure-state-impact-response (DPSIR) model, heavy metal pollution index, ground water, national environmental quality standards

Introduction

Industrialization has negatively impacted human health in several ways but on the other hand, the population has gathered plenty of benefits from the improved employment rate and progressing living standards (Indra and Choudhary, 2004). Industries manufacture products which satisfy the growing requirements of a population but the other hand waste from several processes contaminate soil and water, affecting humans in return (Adriano, 2001). However, insufficient environmental awareness, poor management and weak enforcement of environmental laws have further exacerbated industrial pollution (EPA, 2022).

Due to lack of planning, most developing countries don't monitor their industries properly to protect their environment. This can be carried out by using various industrial abatement procedures. The information they have is either inadequate or obsolete and limited experienced personnel are available to administer different sections of the plants (Oketola and Osibanjo, 2011). Addressing this issue requires a systematic approach, including pollution assessment at the unit level and the implementation of waste reduction strategies (Rathore, 2013).

Millions of people in Lahore are challenged with the dilemma of untreated groundwater polluted with heavy metals from a passing storm-water channel called Sattu Katla (Fig. 1). This channel is 1200 inches wide and measures 672000 inches in length, streaming through nearly all of Lahore before falling into the Hudiara drain escorting it to the river Ravi adjoining Khudpur. All the industries in Kot Lakhpat release their waste water in Sattu Katla channel which is in close proximity to Township, a residential area (Javaid *et al*., 2021). The channel has 110 cusecs of discharge that falls into the Hudiara drain along with wastewater from 8 other major drains of the city. The water further downstream is used for irrigation. Though, the untreated water is not reclaimed or recovered for any industrial purposes. The contamination of water has also led to in degradation in quality of life. The water pollution dilemma is further exacerbated by the illegal dumping of solid waste, forming a fetid-smelling atmosphere due to the sewage, dirty water, refuse and effluents for the neighbouring residential areas (Javaid *et al*., 2024).

*Author for correspondence;
E-mail: drranaamjad@gctownship.edu.pk

Quaid-e-Azam industrial estate was built upon 575 acres of land in 1960. A number of industries including textile, leather, rubber, footwear, utensils, garments, food and drinks, soap, pharmaceutical, iron and steel and hardware are established here. About 512 industries are present in the Quaid-e-Azam industrial estate, out of which 267 are large industries and 245 are small industries. Quaid-e-Azam industrial estate is located on Kasur road as shown in (Fig. 1), having an estimated population of 155,366 according to the 1998 census. The population density is 325 persons/ha. The nearest village is Tahatta village positioned about 3 Km across the railway line while the adjacent town is township, about 300 yards, across the Madre-Milat road. Effluent from these industries falls into the Sattu Katla drain which collectively generates about 57, 200 m^3 of wastewater daily impacting heavily to water pollution in the zone area (Iqbal *et al*., 2024).

Heavy metals such as lead, mercury, cadmium, nickel, chromium and other toxic organic chemicals or phenolic compounds discharged from textile, pharmaceutical, oil, soft drinks and other industries are known to affect the surface and ground waters. It was reported that heavy metals are both mutagenic and toxic so their direct contact to humans and other organisms is unsafe area (Jadoon *et al*., 2024). The most common approaches that can be employed for the quantification of heavy metals are atomic absorption spectroscopy (AAS), inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled plasma - optical emission spectroscopy (ICP-OES) (Bendakovská *et al*., 2016).

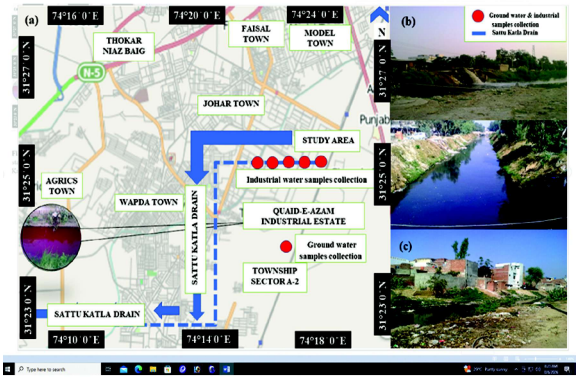


Fig. 1. Area surrounding the Sattu Katla drain. **(a)** map showing route and study area of Sattu Katla drain starting from QIE and passing by township and **(b)** release of industrial effluent directly into Sattu Katla, **(c)** Sattu Katla leading to township sector A2.

Driver pressure state impact response (DPSIR) model is a useful tool for assessing linkages between environmental and socio-economic problems, consequently relationship between the natural resources, human activities and strategists are studied in detail (Zhao *et al*., 2024).

Material and Method

Sample collection. The study area and the drain itself are positioned at latitude of 31° 23' 4 2" N-31° 31' 0" N and at longitude of 74° 13' 10" E-74° 24' 24" E (Majeed *et al*., 2018). Waste water samples were collected (triplicates) using the grab sampling technique from a number of different industries in Kot Lakhpat from the point of discharge in 500 mL plastic bottles according to EPA methods. Prior to sample collection the plastic bottles were washed with dilute HCl and later rinsed twice using distilled water. Afterwards they were dried at 110 °C for an h and cooled down to room temperature (Ohanwemadu *et al*., 2025). Two samples (triplicates) were collected from each industry (oil and ghee, soft drinks, plastic, pharmaceutical and textile) with an interval of 30 min and then returned to the laboratory for analysis. Furthermore, 50 samples were collected from sector A2 of township, 25 from each block 2 and block 5 in summer season. All of the samples were labelled/handled using standard environmental protection agency (EPA) procedures for the investigation of groundwater and effluent, additionally quality control (QC) guidelines were followed as well (EPA, 2025).

Heavy metal determination. The samples collected from industry were analyzed by ICP-OES (Inductively coupled plasma optical emission spectrometry) by ICP-OES 5300 DV Perkin Elmer USA for heavy metals *i.e.* As, Cr and Pb and the ground water samples were quantified by AAS (Atomic Absorption Spectroscopy) Perkin Elmer for Pb, As, Cd, Cr, Zn and Cu. The limit of detection (LOD) of industrial water samples employed for heavy metals (As, Cr, Pb) for ICP-OES ranged between 0.1 µg/L to 1.0 µg/L and for AAS it varied from 0.002 µg/L to 0.05 µg/L.

ICP-OES. The waste water samples from the industries were prepared according to the method (EPA, 2022). After sample preparation the contents were allowed to cool and transferred to a 50 mL volumetric flask where the volume was made up to the mark with distilled

water. The solutions were filtered using filter paper Whatman No.42 and stored in sampling bottles for analysis and later on the protocol was followed for analysis with ICP-OES 5300 DV from Perkin Elmer USA (ICP-Optical emission spectroscopy, 2018). The analytical parameters were followed and wavelengths specified for As was 188.979 nm whereas Cr was 205.552 nm and for Pb 220.345 nm was established. The limit of detection for operation were 1 µg/L for As, 0.2 µg/L for Cr while 1 µg/L for Pb respectively.

Atomic absorption spectroscopy. For operating parameters Perkin Elmer guide was followed (EPA, 2024). After calibration with standards, the ground water samples from township sector A2 (both blocks) were analyzed and graphs were plotted with absorbance on Y-axis and concentration (ppm) on X-axis. The absorbance values of the samples were inserted in the graphs and concentration of the samples were calculated. Analytical parameters for heavy metal detection by AAS are described, the limits of detection (LOD) for Pb (0.05 µg/L), As (0.05 µg/L), Cd (0.002 µg/L), Cr (0.004 µg/L), Zn (0.02 µg/L) and Cu (0.014 µg/L). Correspondingly, the wavelengths of these elements were Pb (283.3 nm), As (193.7 nm), Cd (228.8 nm), Cr (357.9 nm), Zn (213.9) and Cu (324.8 nm) respectively.

Calculation for heavy metal pollution index (HPI). The HPI model was calculated according to the approach (Al-Khuzaie *et al*., 2024) to determine the index of the ground water of township for Pb, As, Cd, Cr, Zn and Cu. Subsequently, weightage (W_i) was computed as the inverse of its maximum admissible concentration (MAC) whereas S_i denotes as the maximum concentration acceptable for drinking water while I_i represents the standard limits.

$$Q_i = \sum_{i=1}^{n} \frac{|M_i - I_i|}{S_i - I_i} \times 100 \quad \text{..... (1)}$$

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \times 100 \quad \text{..... (2)}$$

where:

Q_i is the sub-index and M_i is the monitored value of heavy metal of the i^{th} parameter equation (1). The value specified for life-threatening pollution index (drinking water) HPI equation (2) value is 100 (Al-Khuzaie *et al*., 2024).

Health analysis. Microbiological evaluation of ground water was performed by using Coliscan easy gel kit as described by method (Irvine *et al*., 2024). First of all, the samples (30 from each block) were gathered in a clean bottle and a dropper was used to allocate the ground water sample into a media bottle provided within the kit.1 mL of the sample was used as it was polluted. The bottle was then capped and sample was mixed by swirling the bottle. Later media was poured in the petri dish supplied within the kit and kept away from sunlight. The colonies were counted before 48 h even though most of them appeared after 24 h.

Health survey. In order to identify the health risks a total of 100 residents of township sector A2 were interviewed. The affected areas were monitored for 6 months, October to march for health impacts on the locality. A hundred residents were nominated which were nearest to the industries and were most affected. Data was gathered and questionnaires were filled under supervision of a team of five female students to make sure that every question was understood and answered correctly. The style and language of the questionnaires was kept simple for the ease of people. A local hospital nearby was also visited for health information.

Environmental analysis of QIE *via* a driver pressure-state impact response (DPSIR) model. The DPSIR is a useful tool enabling evaluation of socio-economic and environmental issues. The DPSIR analysis provides recommendations for sustainable and environmentally-friendly measures to the policy makers. The conditions of the Quaid-e-Azam industrial zone were also assessed under the driver pressure state impact response (DPSIR) framework to recognize environmental issues of the area. The driving forces and their associated pressures were identified for two main categories *i.e*., drinking water quality and waste water quality. Then the state of environment and their impacts on inhabitants were also studied (Gule *et al*., 2024).

Statistical analysis. Calculations were conducted in Microsoft excel 2021 and SPSS 20 software while some graphs were illustrated in OriginPro (2024).

Results and Discussion

Quantification of heavy metals in industries. Quantification of selected heavy metals in the industrial drain

by ICP-OES is described in Table 1, which revealed higher concentrations than expected (Fig. 2). The results revealed that in the oil and ghee industry, arsenic (1.72 ± 0.01^{b} mg/L) and lead (1.24 ± 0.15^{b} mg/L) were high whereas chromium was within range *i.e*., 0.81 ± 0.42^{a} mg/L. The heavy metal intensities are presented as mean ± standard deviation where superscripts indicate significant difference at P≤0.05 under different experimental conditions. The NEQs limits for Cr and As are 1.00 mg/L whereas the permissible limit for Pb is 0.50 mg/L. Furthermore, the level of arsenic in soft drinks industry was found to be 1.50 ± 0.15^{c} mg/L and chromium was 0.94 mg/L ± 0.15^{b}, whereas lead was 1.03 ± 0.02^{c} mg/L respectively (significant at P≤0.05). The NEQs limit is clearly lower and the results show slightly higher values. Metals are mostly present in food products naturally or through human interference, so it can be said that in soft drinks industry, raw materials may be contaminated and their excessive use is hazardous for health due to bioaccumulation and biomagnification in human tissues, besides heavy metals do not biologically decay (Eid *et al*., 2024). The results confirm that even though the governments have enacted laws for their proper discharge but mostly they are not obeyed.

As, Cr and Pb are all present in plastic industry samples. In packaging factories, Pb and Cr are usually employed in the manufacture of plastic pellets and crates. Pb compounds are often used as pigments due to their low cost (Colouring Plastics, 2024). These metals were all above their prescribed NEQs in the plastic industry samples except As. The level of lead in plastic industry was found to be 0.08 ± 0.02^{a} mg/L, arsenic was 0.58± 0.02^{b} and chromium was 2.79 ± 0.02^{c} mg/L, significant at P≤0.05 as described in Table 1. According to NEQs the level of arsenic and chromium is meant to be at a maximum level of 1.00 mg/L and lead should 0.50 mg/L in industrial effluent. Most of the samples are surpassing the NEQ limits.

In the pharmaceutical industry, many harmful metals are added to the effluent from different sources, such as raw materials and liquid wastes that are released during batch production (Gadipelly *et al*., 2014). The level of chromium in pharmaceutical industry was found to be 0.86 ± 0.01^{b} mg/L and Lead was 0.32 ± 0.03^{a} mg/L, as exhibited in Table 1. Lastly, As was also detected and its level was 0.51±0.02^{b} mg/L that was

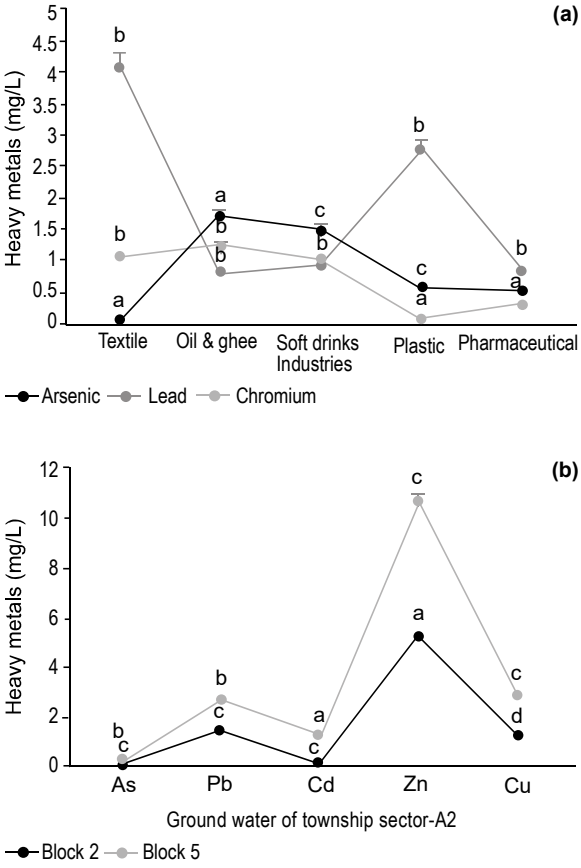


Fig. 2. Heavy metals analysis **(a)** industries **(b)** ground water of township A2.

Table 1. Analysis of the effluents for heavy metals from various industries along with the environmental standards (mg/L)

Heavy metals (mg/L)	Oil & ghee	Soft drinks	Plastic	Pharmaceutical	Textile	NEQs (mg/L)	WHO (mg/L)
Cr	0.81 ± 0.42^{a}	0.94 ± 0.15^{b}	2.79 ± 0.02^{c}	0.86 ± 0.01^{b}	4.10 ± 0.17^{b}	1.00	0.05
As	1.72 ± 0.01^{b}	1.50 ± 0.15^{c}	0.58 ± 0.02^{b}	0.51 ± 0.02^{b}	0.05 ± 0.02^{a}	1.00	0.01
Pb	1.24 ± 0.15^{b}	1.03 ± 0.02^{c}	0.08 ± 0.02^{a}	0.32 ± 0.03^{a}	1.07 ± 0.03^{b}	0.50	0.01

Heavy metal concentrations are stated as mean ± S.E.M of replicates where superscripts indicate significant difference at P ≤ 0.05 under various experimental conditions.

significant at P≤0.05. Pharmaceutical industry samples contained a lesser quantity of heavy metals and are below the NEQs. Usually, Cr is utilized in the textile industry all through oxidizing process and fixing dyes and for chroming procedure while dyeing wool (Tafesse *et al*., 2015). It can be seen that Cr is well above the NEQs. The level of chromium in textile industry was 4.10 ± 0.17^{b} mg/L and arsenic (0.05 ± 0.02^{a} mg/L) whereas Pb was 1.07 ± 0.03^{b} as shown in Table 1. WHO also describes levels for Cr 0.05 mg/L, As 0.01 mg/L and Pb as 0.01 mg/L (Nasircilar *et al*., 2024). Most of our samples have shown high traces of heavy metals. Highest levels of chromium were found in textile (4.10 ± 0.17^{b} mg/L) followed by plastic, soft drinks then pharmaceutical and lowest in oil and ghee which is 0.81 ± 0.42^{a} mg/L. Arsenic was found at maximum level in oil and ghee factory followed by soft drinks, then plastic and pharmaceutical and lowest in textile at 0.05 ± 0.02^{a} mg/L. Similarly, Pb was highest at 1.24 ± 0.15^{b} mg/L (significant at P≤0.05) in oil and ghee industries whereas lowest at plastic factory (Fig. 2). Other industries had medium levels which slightly exceeded the levels of WHO and NEQs both.

A similar investigation showed the high levels of metals in an industrial effluent of Hawassa textile in Ethiopia. The metals detected were chromium, lead and copper and they were quantified as 0.52 to 0.99 mg/L, 1.35 to 4.35 mg/L and 0.14 to 1.00 mg/L respectively (Tafesse *et al*., 2015). The study validates our findings. Another investigation states that alongside Huangshui river in China there are various mining and gold producing establishments which release their industrial effluents near localities and that has impacted the environment greatly. Heavy metals such as Cd was nearly 0.10 µg/L, whereas Cr was above 3.50 µg/L, As 0.28 µg/L and Pb 0.60 µg/L were uncovered, sampling points commencing from factor 1 to 5. The study supports our results (Zhang *et al*., 2022).

A related study with Sattu katla drain faced the same situation. Cu values revealed the concentration to reach till 3.68 mg/L, whereas Zn was 0.13 mg/L. Correspondingly, Pb showed maximum value of 0.82 mg/L, which is not above the NEQs range surprisingly owing to the type of industries present in this area. This study corroborates with our findings and reveal that industries are not following the laws completely and dump their untreated waste water directly into Sattu Katla drain (Majeed *et al*., 2018).

Quantification of heavy metals in ground water. Domestic wastewater, storm water and industrial wastewater finds its way into the Sattu Katla drain which is commonly used for irrigation. The contaminants from this drain and QIE also percolate into the ground water in the surrounding areas posing a serious threat to the resident's health. So, in order to quantify heavy metal levels, 50 samples of groundwater from township area were tested by AAS for As, Pb, Cd, Cr, Zn and Cu (Table 2). The study showed that some samples exceeded the heavy metal levels in block 2, hence they were recorded as, as (0.13 mg/L), Pb (1.47 mg/L), Cd (0.15 mg/L), Cr (0.09 mg/L), Zn (5.27 mg/L) and Cu (1.32 mg/L) respectively (significant at P≤0.05). Results from block 5 were also noted down as exposed 0.18 mg/L, Pb 1.24 mg/L, Cd 1.13 mg/L, while Cr 1.24 mg/L, Zn 5.39 mg/L and Cu 1.59 mg/L (significant at P≤0.05). The trend for block 2 was described as Zn < Pb < Cu < Cd < As < Cr whereas block 5 demonstrated Zn < Cu < Pb < Cr < As < Cd. It explains that the maximum value of heavy metals by block 2 was shown by Zn 5.27 mg/L and minimum by Cr 0.09 mg/L, block 5 also exposed Zn having the highest value at 5.39 mg/L and lowest by Cd 1.13 mg/L. The standards for drinking water are defined by both NEQs and WHO. The NEQs permit As (= 0.05 mg/L), Pb (= 0.05 mg/L), Cd (0.01 mg/L), Cr (= 0.05 mg/L), Zn (5.00 mg/L) and Cu (2.00 mg/L) whereas WHO states that heavy metals should be within range, as and Pb should be 0.01 mg/L, Cd 0.003 mg/L, Cr 0.05 mg/L while Zn 3.00 mg/L and Cu 2.00 mg/L (Fig. 2). The comparison shows that WHO has more safer levels for drinking water. Nevertheless, some of samples in our experiments have exceeded these values particularly Zn, Cr, Cd and Pb. Cu was within the safe limits for both of the blocks way below 2 mg/L. These could be present due the industrial estate adjacent to these towns or it can be assumed that zinc in ground water may have been adsorbed from pipes which are usually galvanized. Block 5 showed slightly elevated values for heavy metals in comparison to block 2 probably due to its location (Table 2).

A related study with Sattu Katla drain exposed high values for Pb in ground water which reached up to 1.56 mg/L whereas the allowed limit is 0.05 mg/L. Furthermore, Cr revealed higher concentrations of 0.39 mg/L which most probably caused due to its leakage into the water heads of the area but only = 0.05 mg/L is permissible. The Cd levels spiked upto 0.19 mg/L whereas the limit is 0.01 mg/L. Later copper values were also

quantified which is 0.04 mg/L and were under the limits (2.00 mg/L) (Haydar *et al*., 2016). Here again most of the drinking water samples are above the NEQs and WHO limits which verifies with our findings.

Heavy metal pollution index (HPI). By considering heavy metal levels, water quality can be easily estimated through the HPI method as shown in Table 2. HPI has been previously reported (Al-Khuzaie *et al*., 2024). The HPI of the groundwater of township sector A2 block 2 was 34 whereas HPI of block 5 was 81. Block 2 is located near the Sattu Katla drain resulting in a relatively lower HPI as compared to that of block 5 (Table 3). The higher HPI of block 5 may be attributed to its greater proximity to QIE as it is located only 300 yards from QIE. Hence its residents have a higher risk of contracting serious illnesses related to heavy metal pollution including kidney failure, cancer of vital organs, mental retardation and even death (Yüksel *et al*., 2024). The HPI describes the level of contamination due to heavy metals in a water body. In a study relating to Euphrates river HPI was measured along different points (40) to evaluate the pollution caused due to heavy metals. Towards south of the river heavy metal pollution started to elevate, at sample point 1 it was 40 HPI but as the investigation was taken further it reached up to 100 at point number 28. Maximum HPI was exposed at point 38 where it reached 150 which is alarming, after this at point 40 it declined to 140. It confirms that

Table 2. Descriptive summary statistics for heavy metals (mg/L) in ground water of township area

Sector A2	Parameter	Max	Min	Mean	Median	SD	MAC	%>MAC
Block 2	As	0.13	0.00	0.03	0.05	0.03	0.010	200
	Pb	1.47	0.01	0.11	0.05	0.28	0.002	5400
	Cd	0.15	0.01	0.04	0.01	0.03	0.003	1233
	Cr	0.09	0.00	0.04	0.05	0.03	0.05	0
	Zn	5.27	0.03	2.53	2.58	1.75	5.000	0
	Cu	1.32	0.00	0.30	0.05	0.46	1.000	0
Block 5	As	0.18	0.00	0.03	0.05	0.04	0.010	200
	Pb	1.24	0.00	0.12	0.05	0.42	0.002	5900
	Cd	1.13	0.00	0.06	0.01	0.39	0.003	1900
	Cr	1.24	0.00	0.27	0.05	0.44	0.050	440
	Zn	5.39	0.01	3.17	4.00	2.09	5.000	0
	Cu	1.59	0.00	1.7	1.12	0.60	1.000	0

Table 3. The HPI of the groundwater and its calculation for block 2 and 5

Sector A2	Parameter	M_i	W_i	S_i	I_i	Q_i	$W_i \times Q_i$	MAC
Block 2	As	0.03	20.0	0.05	0.01	50	1000	0.050
	Pb	0.11	500.0	0.05	0.10	25	12500	0.002
	Cd	0.04	333.0	0.01	0.03	50	16650	0.003
	Cr	0.04	20.0	0.05	0.05	0	0	0.050
	Zn	2.53	0.2	5.00	3.00	23.5	4.7	5.000
	Cu	0.30	1.0	1.00	2.00	170	170	1.000
			$\sum W_i = 874.2$				$\sum W_i \times Q_i = 30324.7$	HPI = 34
Block 5								
	As	0.03	20.0	0.05	0.01	50	2000	1000
	Pb	0.12	500.0	0.05	0.10	40	120000	20000
	Cd	0.06	333.0	0.01	0.03	150	266400	49950
	Cr	0.27	20.0	0.05	0.05	0	0	0
	Zn	3.17	0.2	5.00	3.00	8.5	170	1.7
	Cu	1.7	1.0	1.00	2.00	30	120	30
			$\sum W_i = 874.2$				$\sum W_i \times Q_i = 70981.7$	HPI = 81

these zones are a serious concern and threat for the population surrounding that area and corroborates with our findings (Al-Khuzaie *et al*., 2024).

In a related study with heavy metals in the ground water near Egypt's northwestern desert it was found that the HPI reached 111.7 and later to 7274.5 which was calculated after experimenting with a total of eight heavy metals such as Mn, Cd, Cr, Fe, Cu, Pb, Zn and Ni nevertheless the situation is alarming. HPI can be classified into different categories and water quality can be examined. On a scale of below 25 the water is of excellent quality whereas 26 till 50 shows poor condition, HPI from 51 till 75 is categorized as very poor while 76 to 100 is a serious threat to a certain population (Eid *et al*., 2024).

Health analysis. Quaid-e-Azam industrial estate is facing serious waste water issues. Effluents are directly discharged into the Sattu Katla drain. Industrial units collectively generate about 57, 200 m^3 of wastewater daily, contributing heavily to water pollution in the area and there are no waste water treatment plants to reduce pollution.

Microbiological evaluation. Microbiological evaluation was carried out by analyzing tap water samples from both the locations hence 60 samples were collected. Tap water samples from township were collected for microbial evaluation from sector A2 block 2 which is nearest to the industrial drain and block 5 as it is nearest to the industrial area. *E. coli* (cfu) colonies grew as purple/blue spots and coliforms (cfu) appeared as pink spots. The result showed that more Coliforms (cfu) and *E. coli* (cfu) were present in block 5 as compared to block 2 of sector A-2 township as seen in Table 4 and Fig. 3. More colonies of *E. coli* (25 ± 0.27^{c} /100 mL) (significant at $P \leq 0.05$) were present in block 5 than 2 whereas greater number of coliforms were uncovered in block 2 (21 ± 0.28^{b}/100 mL) although some samples were clear. Contamination of coliform bacteria can cause diseases related to intestines like dysentery, hepatitis, typhoid fever and cholera etc. (Yüksel *et al*., 2024). Residents of the area should use methods of prevention like boiling drinking water before use and adding filters so that they can stay safe (Ameen, 2019). In a case study in Charsadda, tap water was analyzed for coliform bacteria. The result ranged from 0 to 5/100 mL. Tap water of some villages named Yousaf Khanai, Gandheri and Spalmai were tested for coliform bacteria, all of the samples showed the presence of total coliform bacteria in Charsadda, whereas in Shabqadar, water samples were also contaminated with coliform bacteria which validates our findings (Khan *et al*., 2013). In a similar case three areas of Peshawar were tested for the occurrence of coliforms, namely nauguman, charsadda bazaar, sardaryb and charsadda bazar. Sample from Nauguman showed the presence of 100 cfu/100 mL whereas Charsadda bazar revealed 120 cfu/100 mL lastly Sardaryb exposed 20 cfu/100 mL which is most definitely unfit for consumption (Amin *et al*., 2022). It confirms that tap water of this area is highly polluted and is distressing the inhabitants of zone. According to world health organization (WHO) guidelines, not even a single colony of bacteria should be present in water meant for drinking (WHO, 2023).

In a case study in Phnom Penh, Cambodia, some samples gave high results and the two of them reported that *E. coli* in drinking water was 19, 200 cfu/100 mL and 1,140 cfu/100 mL respectively. In nearby areas more samples had high *E. coli* which ranged from 0.03 cfu/100 mL up to 332 cfu/100 mL which is quite alarming and the governments are making efforts to reduce this and provide the residents with clean drinking water (Irvine *et al*., 2024).

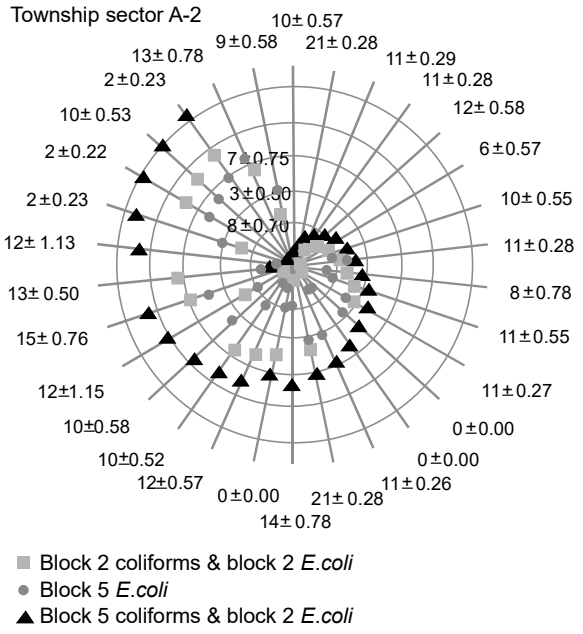


Fig. 3. Radar graph depicting the intensity of coliforms and *E. coli* (cfu) in the ground water of both blocks of township A2.

Health survey: township (sector A2). A total of 100 residents from sector A2 participated in the health survey. A doctor from a nearby clinic diagnosed several families with waterborne diseases. Among the surveyed families, 56% reported falling ill, while 44% did not. Residents stated that they fall ill once or twice every six months due to tap water contamination, leading to medical expenses ranging from a few hundred to a thousand rupees per month.

Among the 100 surveyed residents, 64% were female and 36% were male. The use of a tube well to bring water to their homes was the most common method with 98% using it. 2% of the interviewees said that they used a hand pump to acquire water. When asked if they were satisfied with the quality of their water, 59% replied 'yes' and 41% replied with a 'no'. About 31% classified their water quality as good, 42% as medium and 27% felt it was poor. 89% of the interviewees described their water as transparent, 9% described it as a pale yellow while 2% described it as slightly pale yellow with reddish precipitates. When asked if it was sweet or brackish in taste, 87% said it was sweet, while 13% of the interviewed persons said it was brackish. About 98% said their water had no odour, while 2% said it had an odour. When questioned about whether any family members had been diagnosed with any water borne disease, 56% were in agreement whereas 44% stated otherwise.

Table 4. Quantification of *E. coli* (cfu) and coliforms (cfu) in ground water of township in block 2 and 5

Sample no.	Block 2		Block 5	
	E. coli (cfu) (Mean, SD)	Coliforms (cfu) (Mean, SD)	*E. coli* (cfu) (Mean, SD)	Coliforms (cfu) (Mean, SD)
1	10 ± 0.57^{b}	0 ± 0.00^{b}	25 ± 0.27^{c}	11 ± 0.28^{a}
2	21 ± 0.28^{b}	0 ± 0.00^{b}	13 ± 0.76^{b}	11 ± 0.27^{a}
3	11 ± 0.29^{b}	0 ± 0.00^{b}	12 ± 0.57^{b}	9 ± 0.28^{a}
4	11 ± 0.28^{a}	5 ± 0.56^{b}	11 ± 0.27^{b}	7 ± 0.78^{c}
5	12 ± 0.58^{b}	7 ± 0.76^{b}	11 ± 0.28^{b}	5 ± 0.57^{b}
6	6 ± 0.57^{b}	9 ± 0.27^{b}	13 ± 0.78^{b}	6 ± 0.76^{b}
7	10 ± 0.55^{c}	8 ± 0.78^{b}	11 ± 0.28^{a}	4 ± 0.88^{b}
8	11 ± 0.28^{c}	3 ± 0.55^{b}	11 ± 0.26^{b}	9 ± 0.38^{b}
9	8 ± 0.78^{b}	5 ± 0.58^{b}	11 ± 0.27^{b}	8 ± 0.76^{b}
10	11 ± 0.55^{a}	12 ± 1.14^{b}	11 ± 0.28^{b}	4 ± 0.87^{b}
11	11 ± 0.27^{b}	12 ± 1.15^{b}	0 ± 0.00^{b}	1 ± 0.51^{b}
12	0 ± 0.00^{b}	0 ± 0.00^{b}	12 ± 0.58^{b}	3 ± 0.52^{c}
13	0 ± 0.00^{b}	7 ± 0.76^{a}	12 ± 0.57^{c}	7 ± 0.58^{a}
14	11 ± 0.26^{b}	3 ± 0.50^{a}	0 ± 0.00^{b}	2 ± 0.23^{b}
15	21 ± 0.28^{b}	6 ± 0.54^{b}	0 ± 0.00^{b}	0 ± 0.00^{b}
16	14 ± 0.78^{a}	0 ± 0.00^{b}	11 ± 0.28^{b}	6 ± 0.57^{b}
17	0 ± 0.00^{b}	11 ± 0.28^{b}	11 ± 0.28^{b}	0 ± 0.00^{b}
18	12 ± 0.57^{b}	3 ± 0.88^{c}	13 ± 0.76^{c}	2 ± 0.24^{b}
19	10 ± 0.52^{b}	4 ± 0.86^{c}	13 ± 0.78^{a}	4 ± 0.53^{b}
20	10 ± 0.58^{b}	0 ± 0.00^{b}	12 ± 0.56^{a}	8 ± 0.78^{b}
21	12 ± 1.15^{b}	5 ± 0.58^{b}	11 ± 0.28^{b}	6 ± 0.56^{b}
22	15 ± 0.76^{b}	7 ± 0.75^{b}	12 ± 0.55^{b}	5 ± 0.58^{b}
23	13 ± 0.50^{b}	6 ± 0.56^{b}	11 ± 0.27^{b}	9 ± 0.28^{b}
24	12 ± 1.13^{b}	0 ± 0.00^{b}	13 ± 0.76^{d}	7 ± 0.76^{a}
25	2 ± 0.23^{b}	5 ± 0.58^{b}	0 ± 0.00^{b}	1 ± 0.50^{c}
26	2 ± 0.22^{b}	2 ± 0.23^{a}	9 ± 0.27^{c}	4 ± 0.86^{c}
27	10 ± 0.53^{b}	5 ± 0.57^{a}	7 ± 0.76^{b}	3 ± 0.83^{c}
28	2 ± 0.23^{b}	3 ± 0.87^{a}	5 ± 0.57^{b}	2 ± 0.22^{d}
29	13 ± 0.78^{c}	4 ± 0.86^{c}	3 ± 0.75^{b}	0 ± 0.00^{b}
30	9 ± 0.58^{c}	5 ± 0.58^{c}	0 ± 0.00^{b}	0 ± 0.00^{b}

Microbial assessment is presented as mean ± S.E.M of replicates where superscripts indicate significant difference at $P \leq 0.05$ under various experimental conditions.

The survey also inquired about diseases affecting residents between October and March (Fig. 4). The results revealed that 15% of the residents reported dengue, while 9% had malaria, 8% developed hepatitis, 6% said stomachache, 5% said typhoid, 3% said diarrhea, 3% said jaundice and 2% of the interviewees said dysentery had been contracted by people in their household. Bronchitis, asthma, cholera and other diseases were contracted by 1% each of the interviewed people. However, skin cancer and fluorosis which are known to be caused by polluted water were not found in this area but digestive tract cancer was found in one household (Fig. 4). A local hospital was visited for information regarding the health of local people. The doctor mentioned that this particular area has high disease/illness rate as compared to other area. More patients belong to this area as compared to rest of the sectors in this town.

These results show that while there are skin and internal body diseases, the diseases that are the most common are not only caused by water or the pathogens and chemical pollutants in it but are due to external agents as well *i.e.*, mosquitoes, which lay eggs in the drain water and act as carriers of the dengue and malaria. During further questioning. It had been learnt that 65% of the interviewees don't use any methods of disinfection for their water, while 35% did. These methods of disinfection included boiling which was employed by 27% of the interviewed people, filtering in 7% of the interviewee's households and 1% used alternate methods.

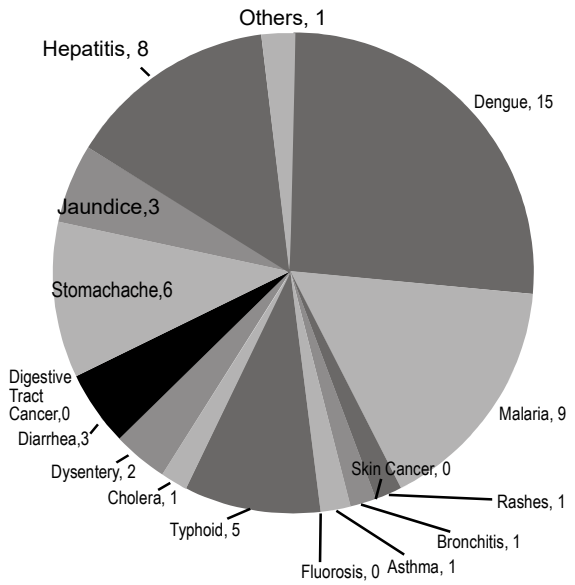


Fig. 4. Types of diseases uncovered at township sector A2.

People who sought medical attention accounted for 89%, while 11% of the interviewees reported to have not sought medical attention. When asked about preventive measures against dengue and malaria, all respondents reported taking action with 35% of the residents securing doors and windows, 23% using coils, mats and sprays, 9% had covered water surfaces, 7% were using mosquito nets whereas 7% were using other methods.

A related study disclosed that 42% of the groundwater samples surpassed the WHO limits and heavy metals such as Cr and Pb levels were high in particular due to the industries nearby. The effluent leaches and ends up in the Sattu Katla drain that is sometimes utilized for agriculture leading to respiratory and gastrointestinal problems including cancer etc. (Iqbal *et al*., 2024).

Awareness among people. Although awareness about pollution and the environment has steadily increased, most people still have a very vague idea of how pollution is harmful and how their lifestyles contribute to it. Many people don't see the link between their lifestyles and pollution thus they disassociate themselves from the idea that they could possibly be part of the problem and pollution is impacting the entire community. It is the responsibility of every person to care for the environment and take action against the structures which promote environmental damage. The institutions which have more influence and a wider audience need to address the industrial divisions on prioritizing environmental safety and to encourage frequent government monitoring to ensure safety regulations are being followed. Awareness campaigns in multiple languages, conducted through schools, community centers and workplaces, can help people make more conscious environmental choices.

Sustainability. Industries are a major source of pollution (Fig. 5). Many times, industrial owners are unaware or indifferent to the concept of sustainability or neglect it if they consider it too expensive or limiting to their businesses. Sustainable criteria should be introduced while planning an industry and evaluations must be carried out to calculate potential losses, costs or risks. All levels in the organization of the industry are involved in contributing to operational efficiency. The entire staff should contribute to sustainability by minimizing resource consumption (*e.g*., water and fuel), maintaining machinery for longevity and recyclability and prioritizing biodegradable materials to reduce pollutants.

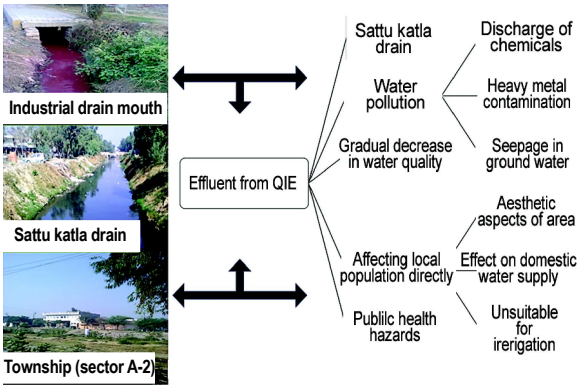


Fig. 5. A network diagram showing impact, causes and consequences in township area due to industries nearby.

Driver pressure state impact response (DPSIR) model. Driving force indicators don't seem to be very responsive (Fig. 6), they comprise of poverty, urbanization, agricultural expansion, upgraded lifestyle, generation of energy, increased employment rate, support for local industry, challenges of industrialization and upgrading and improving technology to enhance profitability for economic growth. The pressure is created by the human population on the environment itself like exploiting resources, releasing pollutants in the environment and usage of land for different purposes. The pressures on the environment (Fig. 6) include Pollution (air, noise, water, land), solid waste generation + disposal, electricity, odour (related to effluent) and need for skilled workers. There are several pressures on water environment due to QIE. The workers at QIE are roughly 50,000 both skilled and unskilled. The main water source for the industries is ground water which is delivered by two sources *i.e.* water and sanitation agency (WASA) supply lines and via QIE overhead water tanks. On a regular basis 225 gallons/ day is used whereas QIE overhead water tanks that installed 500 yards away from the QIE head office, provide the estate with 1 Million gallons of water. These pump water from a depth of 750 feet underground and the water is clean. Water quality is tested by the Pakistan council of research in water resources (PCRWR). The WASA supply lines provided 1 Lakh gallons of water but has now stopped direct pumping as its water is contaminated with sewage. Moreover, pressures due to wastewater causes health problems from the pollutants pouring in from the chemical and industrial processes. These solvents and toxic substances are directly discharged into the streams and rivers, reducing oxygen levels and harming aquatic life.

The state of wastewater environment has made matters worse for the community. The Sattu Katla drain has become a bother for the residents. Impact indicators react even slower than state indicators. When the impacts are felt, it is usually too late for action. Consequently, wastewater has affected groundwater quality which is of great concern as most of the community uses groundwater for drinking purposes. By taking action against the processes which damage our environment. Then environmental destruction may be limited. In order to reduce pollution a waste treatment layout should be prepared and activated sludge would be best in this situation. A combined treatment plant would not only reduce pollution and save money but also ensure sustainability. Moreover, in QIE waste minimization technique can also be used as 30% wastes can be reduce through this technique and is effective. Pretreatment need to be done by industries themselves for example

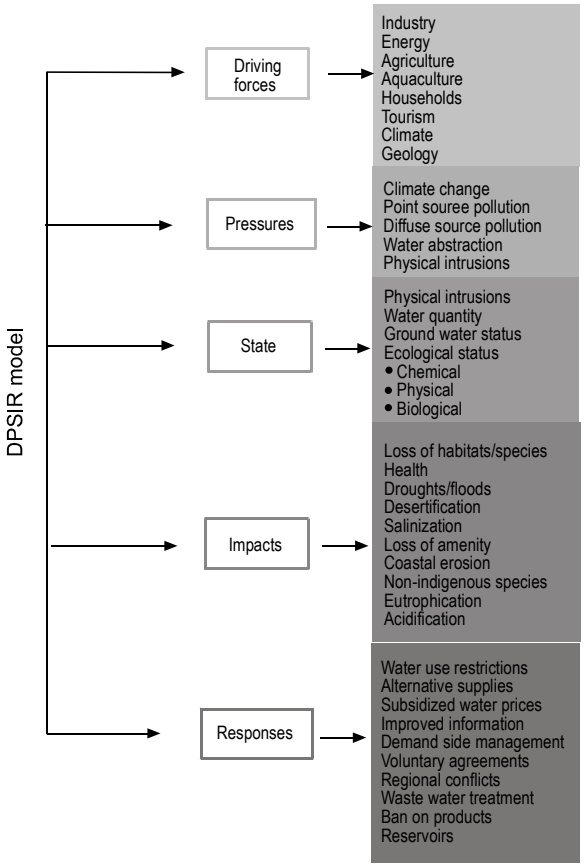


Fig. 6. DPSIR model for QIE.

they can do screening to prevent the sewerage system, remove toxicants etc. Activated sludge process (ASPs) is an efficient and a reliable process to deal with the waste-water.

Wastewater treatment (response) will reduce the pollution by many folds. Industrial units are the main sources of waste water in QIE and also the nearby residential area township and Tahatta village. Keeping all that in mind wastewater treatment plants (WWTP) should be installed in the industrial estate at the distance of 500 yards from the head office and the area required for construction is 20 acres/170 canals. Before the wastewater is transported to the WWTPs, it will be held in the oxidation ponds to reduce their waste content.

One option could be preliminary treatment such as screening and grit removal. Screening shall be completed using mesh screens to remove debris and rags and grit chambers will be used to get rid of grit, sand and coarse suspended particles. Primary treatment will include pre-aeration to remove odors and primary sedimentation to eliminate suspended solids and organic matter whereas the secondary treatment will reduce organic matter content in the wastewater by using activated sludge process (ASPs). ASPs use the assemblage of micro-organisms to eliminate biological oxygen demand (BOD) present in the wastewater.

ASPs require lesser land and more efficient and thus are the best available biological treatment option. Later secondary sedimentation will take place to remove the sludge produced in the ASPs. A rapid sand filter will further remove any suspended solids in the wastewater stream in the advanced treatment. Disinfection by chlorine shall be done to remove remaining pathogens. Rapid sand will be used because it is efficient and requires less space. Moreover, WWTP is being designed for heavy discharge so rapid sand filters are most desirable. Lastly the process of flotation to remove oil and grease will be added in the primary treatment. Screening can be seen in (Fig. 7a) in this chamber coarse solids and heavy inorganic materials will be removed. Aerated equalization tank will provide flow balancing though aeration tank microorganisms will utilize the pollutants as food. Coagulation and flocculation will deal with destabilized particles while in clarifiers microorganisms and solids will settle as activated sludge.

Second option for WWTP in QIE is the establishment of stabilization ponds as there is enough space available for it. After primary treatment (screening, grit removal, aeration and primary sedimentation) waste water will be sent to stabilization ponds. A suitable option will be series and parallel combination of facultative and maturation pond system. Contaminants such as BOD and metals are removed from the primary effluent through the processes of settling, sedimentation, absorption, chemical oxidation/reduction, precipitation, photodegradation, aerobic/anaerobic biodegradation, phytoaccumulation, phytovolatilization and evapotranspiration.

In the WWTPs, sludge is collected from primary and secondary sedimentation tanks (Fig. 7b). The treatment for sludge shall be carried out in the WWTPs using the processes like thickening using centrifugation processes will be done so as to reduce total sludge volume by removing part of the moisture content of sludge. Conditioning of the sludge will be done through thermal heating. This process will help stabilize, sterilize and dewater sludge. Composting of the sludge will be done to degrade organic matter, destroy enteric micro-organisms and reduce volatile solids to make the sludge an inert but efficient soil conditioner.

A DPSIR model was also studied consisting of 19 indicators at Macao and Zuhai, China, depicting adverse impacts in the vicinity. Subsequently upgrading of treatment plans reduced water scarcity and elevated their socio-economic conditions at the same time (Bai *et al*., 2024). Similarly, another case was also identified in Henan (province) and the outcome disclosed that activities such as farming, sewage treatment, daily water consumption in households and industries were the major pressures on the water resources. However, sustainability and proper allocation of resources are

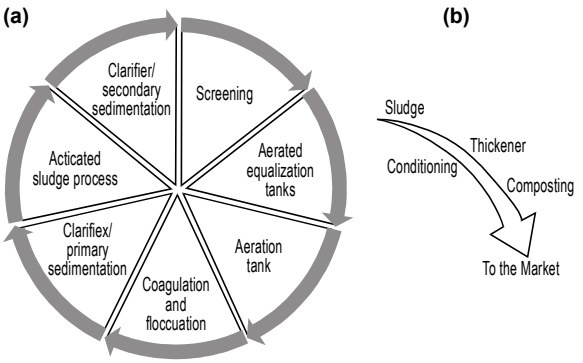


Fig. 7. Schematic diagram. (a) wastewater treatment and (b) sludge treatment.

necessary measures for upcoming years (Zhao *et al*., 2024). Another closely related study located at Sithonia Peninsula (north Greece) also pointed out the water quality indices along with DPSIR model. They identified that the pressures mainly included the presence of olive factories near by also dumping sites within the vicinity, while waste waster collection centres were also present. Moreover, tourism was also one of the main pressure points in that zone. Outcome also depicted the mixing of seawater in these localities which was affecting the quality of the ground water *i.e*. Na^+/Cl^- values ranged from 0.12 to 1.48 whereas Cl^-/SO_4^{2-} ion ratios were calculate to be 0.91 to 186.58 (Parastatidou *et al*., 2025).

Similarly, another extensive research was carried out near pearl river delta, China utilizing DPSIR framework with five criterion layers followed by twenty-one 21 indicators for environmental assessment and concluded that Dongguan area should devise plans and implement strategies to recover the land and focus on its remediation. This also includes proper monitoring, implementation of laws, supervision and public awareness (Deng *et al*., 2025).

Conclusion

The findings identify the environmental implications of an industrial estate including the ground water of township residential area sector A2. The outcome revealed that the ground water was contaminated with high levels of heavy metals *i.e*. arsenic, lead, cadmium, chromium and copper that is attributed to its close proximity to Quaid-e-Azam industrial estate (QIE). The following conclusions were also drawn. The industrial effluents of QIE, released into the nearby Sattu Katla drain and seeping into ground water, had some heavy metal concentrations above national environmental quality standards (NEQs). It was also determined by HPI method that the residents of block 5 of sector A2 were at a much greater risk as compared to those of block 2 as its location is closer to these industries. This method can be used to calculate heavy metal pollution index anywhere in the world and it is simple and accurate. After careful health analysis it can be observed that this zone near Quaid-e-Azam industrial estate Lahore is polluted. Different types of diseases were contracted by the people within a period of six months (October-March). The diseases that were common in both of the locations were dengue, malaria, hepatitis, stomachache, typhoid, diarrhea, jaundice and dysentery. The DPSIR model shows the link between industrialization and the risks posed to human health by environmental contamination. Industries who are releasing toxic substances above their limit should be fined and people of the nearby areas should be trained to cope with these situations and inform the authorities immediately. Sustainability is the only key that will lead us to a better future and environment.

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Conflicts of Interest. The authors declare that they have no conflicts of interest.

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