Analysis of emerging contaminants: A case study of the underground and drinking water samples in Chandigarh, India

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ABSTRACT

The present report deals with the analysis of emerging contaminants and the quality of drinking and underground water supply in Chandigarh, India. A water sampling monitoring and analysis was conducted by collecting a total of 54 samples of underground & drinking water of Chandigarh to analyse the health risk associated with the spread of emerging contaminants in the water sources. The quality of water samples was also assessed by measuring the colour, odour, temperature, pH, electrical conductivity (EC), biological oxygen demand (BOD), dissolved oxygen (DO), total dissolved solids/ salts (TDS) and hardness. For the estimation of the emerging contaminants (Endosulphan (ES) and Hexachlorohexane (HCH)) in the water samples, an extraction procedure was carried out by dispersive liquid-liquid extraction method followed by analysis using gas chromatography-mass spectrometry (GC-MS). The levels of ES and HCH obtained were compared with the drinking water standards of the Bureau of Indian Standards (IS: 10500). The levels of HCH and ES in all the water samples tested were found to be below the detection limit. It cannot be denied that the industrial discharge and other agencies seems to be complying with the regulations. The Initiatives by the Central and State Govt of India seems to have created sensitivity and awareness among the public specifically among the farmers. The limit of detection (LOD) were 1.0×10^{-3} and 2.4×10^{-3} ppm for ES and, HCH respectively. However, some water pollution indicators such as TDS, EC, DO and total hardness were found to exceed the limits specified by the Bureau of Indian Standards (BIS).

1. Introduction

The global population of the world is expected to exceed 9.8 billion by 2050 (World Population Prospects, 2017). The rapid population growth is expected to have associated impacts such as increased demand for food, water and other basic needs. This, in turn, will put more pressure on the agricultural sector for increased production of food creating added stress on resources such as water and fuels *etc.* (Bierkens and Wada, 2019). About 70 % of the world's accessible freshwater is used for agriculture (Anon, 2016). However, the decreasing availability of drinking water makes it a valuable asset which should be used sensibly. Water pollution pressures brought about by activities such as industrial discharge, agricultural run offs, mining, and sewage disposal, have resulted in the contamination of both surface and underground water resources. Conventionally, groundwater was assumed to be the most unspoiled, cleaner and pristine source of water compared to sur-

face water supply. However, in the past decades, the problems of ground water contamination and pollution are widespread globally (The United Nations World Water Development Report 2017) and developing countries are most affected in particular (Kumar et al., 2014). To overcome this global issue, promising development on waste-water remediation techniques based on different mechanisms such as organic ligand-based metal ion chelation (Vashisht et al., 2020), molecular organic frameworks (MOFs) (Dias and Petit, 2015), nanomaterials (Vashisht et al., 2020), transformation of waste to useful materials (Liew et al., 2019, Yek et al., 2019) etc. have been reported.

India is one of the affected developing countries with 17% of the world's population and 4% of the world's freshwater resources ranking it among the top ten water-rich countries (Yadav et al., 2015, Bhadbhade et al., 2002). However, India is the third most polluted nation in the world and is currently designated as water-stressed by the intergovernmental panel on climate change (IPCC) with current utilizable

freshwater much lower than international standards. Heavy dependence on groundwater, years of limited rains and disproportionate demand for water due to rapid population increase, urbanization and industrialization have put considerable stress on water management (Jain et al., 2004, Sabater et al., 2018). Eighty percent of India's drinking water comes from groundwater, a resource that is depleting and continuously being compromised by large scale discharge of industrial and agricultural effluents, primarily emerging contaminants and toxic metals (Water Aid Assessment, 2017) (Nayak, 2009). Emerging contaminants are naturally occurring or synthetic chemicals which needs to be monitored and regulated in the environment. These contaminants include pharmaceuticals, pesticides, metals, surfactants, industrial effluents, and solvents (Rosenfeld and Feng, 2011). Three EU-listed priority '**emerging contaminants**' (Dichlorodiphenyltrichloroethane (DDT), Endosulphan (ES) and hexachlorocyclohexane (HCH)), represent more than 67% of the total pesticide used in India and their presence in water is causing the spread of antibiotic ingredients, enabling bacteria to develop immunity to antibiotics, and creating superbugs (Gani and Kazmi, 2017).

Pesticides are the chemicals used directly or as mixtures in some solvents to prevent, fight and kill weeds, pests, fungi, and rodents (Giliomee, 2009). The transfer of these harmful chemicals from the site of the application by runoff leads to bioaccumulation in living beings. About 3% of the total consumption of pesticides in the world is in the India. The contamination of surface and groundwater due to excessive use of pesticides is a serious threat to the environment and living beings (Bhadbhade et al., 2002).

The use of pesticides is highest in the Indian states of Maharashtra, Uttar Pradesh followed by Haryana and Punjab. In 2016-17, a significantly increased consumption was recorded in Maharashtra and Uttar Pradesh, while it declined in Punjab and Haryana (Yadav et al., 2015). In a report by Centre for Science and Environment, the packaged bottles of water samples of about 17 different brands in the Delhi region were analysed for 12 organochlorines and 8 organophosphorus pesticides. Among the organochlorines, 94% of all the samples were detected with γ-isomer of HCH (Lindane). 70.6 % of the samples were found to contain DDT. The reason was found to be the water supply to Delhi which is majorly from the river Yamuna, one amongst the most polluted rivers in India. Industrial and domestic waste from the city gets deposited along the bank which was the major contributor to pollution (Mathur et al., 2003).

According to a report by Mittal *et al.* (Mittal et al., 2014), the advent of the Green Revolution in 1965 witnessed a tremendous increase in agricultural productivity. This Green Revolution filled the bread bags with increased production of food and crops such as pulses, wheat, sugarcane, cotton, *etc.* The revolution was based on the introduction of new and chemical fertilizers, pesticides and high yielding seed varieties. Punjab was the hub of this revolution as it made the farmers of Punjab self-sufficient and removed their dependency over other states. However, due to excessive usage of pesticides, the Malwa region in the state of Punjab has recorded in recent times a large number of cancer and reproductive disorder cases. The environmental, occupational and social factors were found to be responsible for such a high pesticide consumption.

The capital city of Punjab and Haryana is Chandigarh which is known for its well-managed, planned infrastructure and architecture in addition to its cleanliness, water supply, electricity, transport, and sanitation facilities. When the 'City Beautiful' Chandigarh was planned, the availability of e subsoil water was adequate to meet the city's requirements. As the population of the city increased, the tube wells dried up and surface water from Bhakra dam main line was deployed to meet the city's water supply requirements. The supply of water to the city of Chandigarh comes from two sources: (i) Surface water from Bhakra Main Canal tapped at Kajauli (27 km from Chandigarh) (ii) Underground water pumped through deep bore tube wells (Municipal Corporation Chandigarh 2017)). Despite the progressive developments, there are villages and rural areas surrounding Chandigarh which lie close to the municipal domestic waste dumping ground and industrial site whose activities usually lead to contamination of the water supply. In addition, the nearby areas lying within 14-20 km of Chandigarh are fields where cultivation of various crops is practiced by farmers. According to Mahajan (2017) and Puri et al. (2014), *many* cases of gastroenteritis were reported because of the contaminated water supply in January 2017. It was identified in the study that mixing of the drinking water with sewage leakage from pipes was the chief reason for the contamination and disease outbreak. The quality of groundwater in the Chandigarh which is the major source of freshwater is susceptible to deterioration due to primitive dumping practices, agricultural activities and rapid industrialization. The nearby states of Chandigarh, i.e. Haryana, Punjab and Delhi have also reported poor quality of groundwater. A comprehensive analysis of the Chandigarh's underground and drinking water has been performed. The main objectives of the investigation were to assess the quality of water and monitor the levels of ES & HCH in the drinking and underground water samples of Chandigarh and nearby region. To our knowledge, no study on the physio-chemical analysis and monitoring of emerging contaminants, ES and HCH in the drinking and groundwater of the Chandigarh is available, however, the reports on examination of physiochemical parameters of the drinking water in the neighbouring cities of Chandigarh are available in literature (Kaushik et al., 2010, Rout and Sharma, 2011, Singh et al., 2010, Gupta and Sunita, 2009, Hundal et al., 2009, Sharma, 2015). In the present work, an investigation of the levels of emerging contaminants and physiochemical parameters has been carried out and interpreted as pollutant pressures.

2. Materials and methods

2.1. Study area

Chandigarh is located at the foot of the Himalayan range. The city beautiful, Chandigarh is fast emerging as one of the most advanced cities in India. It is spread over 114 sq. km, located at Shivalik Foot Hills, surrounded by Patiala ki Rao on the northwest and Sukhna Choe on Northeast. The layout plan of the Chandigarh is as shown in Fig. 1.

The climate of the Chandigarh is sub-tropical with hot summer and cold winter except during the monsoon when the moist air of oceanic origin reaches the areas. The annual rainfall of the Chandigarh is 1061 mm, which is unevenly distributed over the area in 49 days. The southwest monsoon from the last week of June and withdraws at the end of September and contributes 80% of the annual rainfall.

The city has been divided into 6 zones for water supply. Each of these zones is supplied water through independent water works. The Mother water works is Water Works, Sector 39, Chandigarh which receives water from Kajauli and various tube wells. At the water works-39, the canal water received is treated at the water treatment plan. The raw water from Kajauli, Punjab is transmitted through the main transmission to the water treatment plant in Sector-39. The water is then treated, disinfected and stored which is further pumped to five different waterworks. These waterworks further pump the water to the Chandigarh's water distribution system (Tiwari and Bhatia, 2013).

2.2. Sample collection

The sample collection was done during the months of February to June 2019. 1L amber-coloured glass bottles with polytetrafluoroethylene lined screw caps were used for sampling. The sample bottles were rinsed with deionized water and sterilized in hot air oven at 170°C for 1h. Once sterilized, the bottles were allowed to be cooled. A total of 54 samples were collected (Fig. 2). The specific sample point for tap and underground water is shown in figure S1. Tables S1 and S2 represent the location of the sample in terms of Longitude and Latitude and allotted sample IDs for tap and groundwater samples, respectively.
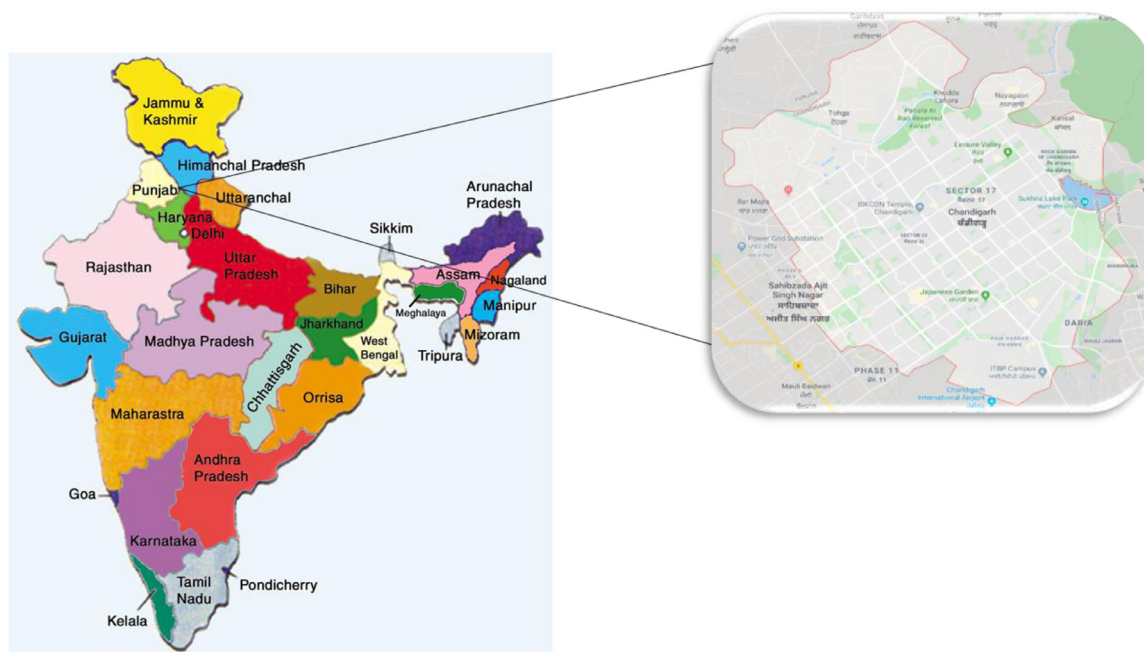
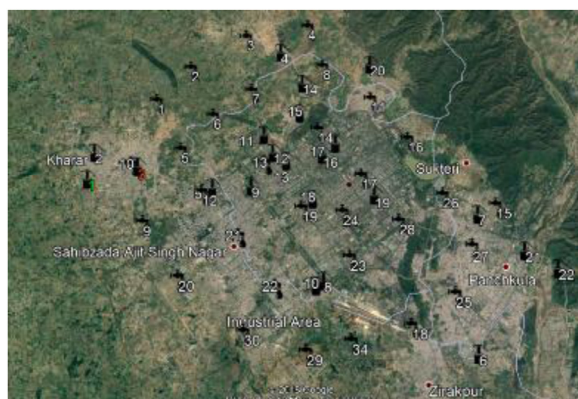**Fig. 1.** Location of the Chandigarh in map of the India.

Fig. 2. Location of all the sampling points of the study area.

2.2.1. Sampling from a tap

To draw a sample from the tap, both the tap and its outlet was cleaned with a clean cloth. The tap was opened until it reached its maximum rate of flow. After, the water flow for 1-2 minutes to clear the service line, tap was closed. After sterilization, the tap was opened again, this time allowing the water to flow for 1-2 minutes at a normal rate. Immediately, the sterilized bottle was held under the water jet and filled up to the shoulder leaving the space in the bottle for shaking to be easier before the analysis. Securely labelled the bottle with, sample location, date, time and sample ID. The bottle was placed into transport box and returned to the laboratory within 24 h.

2.2.2. Sampling from hand pumps, tube wells and borewells fitted with a pump

To collect samples from hand pumps, the pump was operated for at least 20 minutes. Cleaned the mouth of the pump thoroughly and using the same process described for tap, sterilized for a minute with the flame. The pump was operated for further 2 minutes and the sample was taken from the pump.

2.2.3. Sample transportation

The water samples were chilled and made sure that the temperature did not cross 10 ^{0}C. After being transported, the samples were immediately shifted to the refrigerator until the extraction. Water samples were extracted within 24 h of the collection and the extracts were then stored in amber glass vials before the analysis using GC-MS. The EPA recommendations were followed to preserve the samples for various measurements (Table S3)

2.3. Reagents and standards

The standard reference samples of the pesticide ES and HCH were obtained from Sigma-Aldrich and were of high purity grade. The choice of pesticides for the study was based on the statistics of the consumption of pesticides in India. The specifications of the target pesticides are tabulated in Table S4. All the solvents used, including dichloromethane (DCM), hexane, and ethanol were of analytical grade and were procured from Avra synthesis Pvt. Ltd. To carry out calibration studies, solutions of ES and HCH with concentrations 5.0×10^{-2} ppm, 5.0×10^{-3} and 5.0×10^{-4} ppm were prepared by appropriate dilutions of the standard stock solution. Aqueous solutions of standards were prepared by spiking a fixed amount of the working standard. The extraction of the standard solutions was carried out using liquid-liquid extraction procedure, analysed using GC-MS and the recovery % was noted.

2.4. Instrumentation

The analysis was carried out with Thermo Scientific Trace 1300 GC coupled with Thermo TSQ 800 Triple Quadrupole MS. The specifications of the GC-MS instrument used for the studies have been given in Table 1. The temperature was measured using well calibrated digital thermometer. Pico Lab India digital conductivity meter was employed for electrical conductivity meter. The conductivity meter was calibrated using a saturated KCl (0.01M) solution and the temperature was adjusted to 25°C.

Table 1

Specifications of GC-MS Instrument employed for the studies.

Item	Condition
GC	Make-Thermo Scientific Model- Trace 1300GC coupled with Thermo TSQ 800 Triple Quadrupole MS
Detector	BP 5MS
Column	BP 5MS (30 m × 0.25 mm × 0.25 μm)
Pesticide	Organochlorines
Injection Volume	1.0 μL
Injector Temperature	260°C
Carrier gas/ flow rate	Helium gas/1.2 mL/min
Oven Programming	Initial Temp 100°C Hold Time: 1.0 min Temp1: 280°C Hold Time: 13.0 min Rate 15°C/min
Total run time	26 min

2.5. Methods

The on-site analysis of samples was done to note down the colour, odour, pH, and temperature. Rest of the parameters were recorded in the lab.

2.5.1. Colour and odour

The colour of the water sample was noted down by direct observation without any filtration or centrifugation. Only simple visual comparison method was used for colour measurements. It is known that most of the organic and inorganic substances exhibit a characteristic odour. So, all the samples were directly observed for the odour.

2.5.2. Temperature

The behavioural characteristics of the aquatic organisms, solubility of salts, *etc.* are dependent on the temperature. The temperature was noted down with the help of a digital thermometer by immersing it in the water body and allowing sufficient time to get a constant reading.

2.5.3. pH

The pH of water is an index to signify the basicity/acidity of the water sample. The value of any sample may vary in the laboratory and it may not be the same as on the sample site because of the loss or absorption of any gases, sediments, etc. So, the pH value was taken at the time of sample collection. A 100 mL of sample was taken in a beaker and the pH was noted. Before making another measurement, the electrode was rinsed twice. This procedure was repeated thrice to get reliable value.

2.5.4. Total Dissolved Salts (TDS)

The presence of carbonates, hydrogen carbonates, chlorides, nitrates, sulphates of calcium, magnesium, sodium, potassium and organic material contributes to TDS. The higher value of TDS is indicative of the non-potability of the water for drinking purposes.

2.5.5. Electrical Conductivity (EC)

The electrical conductivity of the water is representative of the amount of salts present in it. The high value of the electrical conductivity indicates the presence of the high amount of the dissolved salts in the water sample. It is the measure of the ability of an aqueous solution to conduct electricity. A 100 mL of the water sample was analysed by immersing the cell into the sample. The cell was washed thoroughly with distilled before and after the measurement.

2.5.6. Biological Oxygen Demand (BOD)

The BOD determines the amount of dissolved oxygen required for the organic break down of the organic material by the aerobic organisms. The water sample to be analysed were made sure to be free from chlorine, pH to be in the range of 6.5-7.5 and to have adequate amount of microbiological population.

Specialized barcoded, sequentially numbered, borosilicate glass and chemical resistant 300 mL BOD bottles with no air space were used. One bottle with dilution water as blank was also analysed. The DO was evaluated by using Winkler's procedure (titration method). Each bottle was then kept in dark incubator for 5 days at 20°C. After 5 days the DO reading was again noted. To measure the BOD value of the water sample collected, the constant temperature was maintained (20 ± 1°C) in the chamber. The dilution water was aerated followed by the addition of potassium phosphate, magnesium sulphate, calcium chloride and ferric chloride per 1 L of dilution water to saturate the water with oxygen. The dilution water was placed in a constant temperature chamber to maintain the temperature of 20°C until the analysis and sample dilution begun. A similar procedure was followed for the environmental sample. The sample container was then placed in the temperature chamber and aerated for about 15 minutes. Different dilutions of the sample were prepared and analysed. The sealed BOD bottles containing samples were kept in the incubator for about 5 days at 20 ± 1°C for 5 days. 3 BOD bottles per sample were used.

2.5.7. Total Hardness (EDTA Method)

Ca (II) and Mg (II) ions in the water samples sequester upon the addition of disodium ethylene diamine tetraacetate (Na_2EDTA). Eriochrome Black T was used as an indicator to detect the endpoint which showed red colour in the presence of Ca (II) and Mg (II) ions and blue colour when the ions were sequestered.

2.5.8. Procedure for Extraction of ES and HCH from water samples

For ES (Kaushik et al., 2010): Water samples collected in pre-cleaned and sterilized 500 mL amber-coloured bottles were sealed with stopper covered with aluminium foil. The samples were then extracted using hexane by using a liquid-liquid extraction procedure. A 300 mL water sample was extracted with about 10% NaCl in a separating funnel thrice with DCM (2 × 50 mL) and once with hexane (25 mL), shaking for two minutes and allowing the phase to separate for about 10 minutes. These extracts were dried over sodium sulphate and then in a rotatory evaporator. The dried extracts were then dissolved in hexane and analysed using GC-MS.

For HCH (Dineshkumar et al., 2014): 500 mL of water sample along with 10% NaCl was taken in separating funnel and shaken well to dissolve. This was followed by the addition of about 35 mL of DCM and shaken well. The funnel was placed on a stand for 10 minutes to separate the organic and aqueous layers. The DCM layer was collected in a conical flask. The partitioning procedure was followed twice using 40 mL of DCM again. A partitioning experiment was also performed using 50 mL hexane. The entire organic layer was collected and combined to which 5-10 g of anhydrous sodium sulphate was added. This was then concentrated on the rotatory evaporator to 5 mL. To this extract, 20 mL of hexane was added and again concentrated to 2-3 mL. This concentration process was repeated thrice. The residue was evaporated to dryness. The dried extract was then taken in 1 mL of n-hexane for injection into the GC-MS sampler.

2.5.9. Quality Control (QC) and Quality Assurance (QA)

Adequate QC and QA procedures in analysis are required to obtain reliable results. For pH measurements, before measuring the samples, the pH meter electrode was calibrated with buffers of pH 4.0, 7.0 and 12.0. Similarly, for EC measurements, only glass beakers were used for taking the samples. Calibration was done with KCl-1.41 μmhos/cm before measuring the samples. To measure TDS, a well calibrated digital TDS meter used. For minimum quality control blank reagents, internal standard, and spiked samples were examined. All interferences from glassware and reagents were examined and made sure to be under control by running a blank reagent every time with the sample of interest. For all the samples, the recovery value (Table 2) of all the field replicates was found to fall in the range of R ± 30%. The minimum detection limit was calculated from the calibration curve using three laboratory field

Table 2
The recovery rates obtained for spiked samples.

Pesticide	Spiked	Measured	recovery %	mean recovery (%)	R. S. D. %
HCH	0.200	0.175	87.5	82.0	5.9
	0.400	0.303	75.0		
	0.500	0.418	83.6		
ES	5.000	4.738	94.7	92.0	7.7
	7.000	6.004	85.7		
	9.000	8.608	95.6		
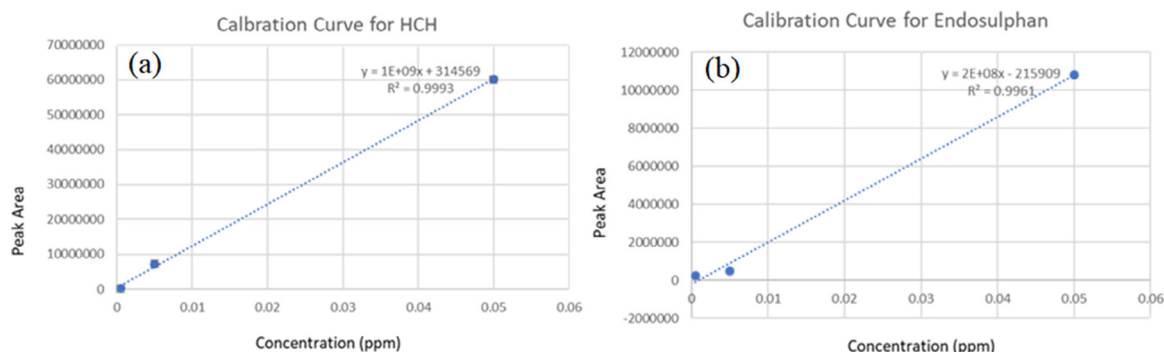
Fig. 3. Calibration curve for (a) HCH and (b) ES.

blanks. The internal library search was also validated for spiked samples and the field samples were then analysed using the library search available within the analysis software.

To perform the recovery studies, aqueous solutions of a known appropriate amount of standard mixture were prepared, extracted and analysed using GC-MS to validate the extraction procedure. The recovery rates were estimated for three different concentrations. The average recovery and relative standard deviation at three concentrations are shown in Table 2. For the method qualification, the specificity of the analytical procedure was checked by analysing a solvent blank and a prepared blank. Calibration curves of each analyte were generated to check the linearity of the peak area versus concentration of HCH and ES. As clear from Fig. 3 excellent linear behaviour was observed for both the cases. Good recoveries were observed by adding a known amount of analyte at different concentrations and respective % of RSD was evaluated (Table 2). All the quality assurance parameters are enlisted in Table S5.

3. Results and discussion

The results of various parameters including both on site and in lab analyses for different water samples collected are tabulated in Table 3. The colour and odour were found to be unobjectionable. The assessment of water quality is essential to get valuable information that is useful for the public, policymakers, and decision-makers to ensure public safety and health. The permissible values and the standards of the drinking water are shown in Table S7.

3.1. Temperature

The temperature of all water samples collected from the tap, tube wells, and hand pumps was found to lie in range 25 to 30°C. (Figs. S2 and S3)

3.2. pH

Although the hydrogen ions do not have any adverse effect on the health, it can cause many further effects such as taste, stained laundry, greenish-blue staining of sinks and household items, reduced efficiency of water-based appliances like geysers, heaters, *etc*. Most of the tap, tube well and hand pump water samples collected for this report were found

to be within the acceptable range of 6.5 to 8.5 as per the guidelines by IS:10500 (Fig. 4a). 52% of samples were found to have a pH value between 7.5 and 8.5. The pH values of the water samples were found to lie between 6.42 and 8.91 with an average value of 7.47±0.38. So, the pH values of all the samples lie between the permissible limits indicating no harmful impact from agricultural and health perspectives. However, the pH values less than 6.5 can affect the aquatic life, formation of necessary vitamins and minerals in humans and more than 8.5 could give salty taste to water in addition to problems such as corrosivity to pipelines, eye irritations and skin problems.

3.3. TDS

To parameterize the salinity of the drinking and groundwater samples, TDS measurements were done. The bicarbonate, chloride and sulphate salts of Ca, Mg, K, Na give rise to the TDS. The permissible limit of TDS for drinking water samples is up to 500 mg/L (Table S7). Most of the water samples were observed to have the TDS value below the prescribed limit. TDS of the study area varied between 120 to 556 mg/L with a mean value of 322.44±88.30 mg/L. Less than 5 % of the samples collected were found to have the TDS value above 500 mg/L (Fig. 4b). However, the values were not extremely higher than the prescribed limit suggesting water suitability for drinking. It is advised to boil the water before drinking. Discharge from these dumping sites could be one of the chief reasons for the contamination of water and deviation of the physiochemical parameters beyond the prescribed limits.

3.4. Total hardness

Another quality parameter is the hardness of the water. The permissible limit of the hardness of water according to guidelines by IS: 10500 is 300 mg/L. The collected water samples from various sites of the study area were found to lie in the range of 100 to 340 mg/L (Fig. 4c) with an average of 173.87±49.28 mg/L. 98% of samples were found to have the hardness values below 300 mg/L which is the prescribed limit by IS: 10500. 33 samples were found to be moderately hard and one sample (sample point 16HP) was found to fall in very hard category (Table S6). Infact, the local authorities have marked the hand pump red. There is a need to stress the proper management of the domestic, industrial and agricultural waste to save the public health. The hardness of the water

Table 3
Various parameters of different sample locations.

Sample ID	pH	Temp ˚C	TDS (mg/L)	DO (mg/L)	BOD ($\times 10^{-3}$) (mg/L)	Total Hardness (mg/L)	Permanent Hardness (mg/L)	EC (μS/cm)	ES	HCH
12 TW	7.56±0.08	28.5	422	6.2	0.4	224	195	955.80±0.43	BDL	BDL
13 TW	7.42±0.20	28.5	289	6.1	0.5	153	129	849.03±0.86	BDL	BDL
5 TW	7.83±0.02	28.5	251	5.8	1.9	133	120	243.86±0.37	BDL	BDL
17 HP	7.40±0.00	28.6	204	5.1	0.2	108	96	827.76±1.68	BDL	BDL
18 TW	8.18±0.07	28.7	252	5.8	1.3	134	128	535.50±0.58	BDL	BDL
16 HP	8.91±0.38	28.5	543	6.3	2.2	340	222	1545.66±3.39	BDL	BDL
11 TW	7.76±0.02	28.7	232	5.6	0.4	123	115	1124.6±3.29	BDL	BDL
9 TW	7.41±0.03	28.6	261	5.8	0.5	138	129	950.33±2.86	BDL	BDL
15 TW	7.83±0.12	27.9	223	6.1	0.3	118	110	703.73±1.91	BDL	BDL
4 TW	7.83±0.08	29.8	556	5.8	0.4	295	278	427.93±5.79	BDL	BDL
14 TW	7.33±0.03	30	484	5.0	0.6	257	249	768.20±1.73	BDL	BDL
1 TW	7.11±0.000	28.4	295	5.8	0.4	156	148	987.30±1.76	BDL	BDL
2 TW	8.12±0.09	28.3	320	6.1	0.2	170	157	508.40±0.54	BDL	BDL
3 TW	7.65±0.02	28.6	274	7.1	0.5	145	138	521.73±3.18	BDL	BDL
10 HP	7.80±0.04	28.9	352	5.8	0.3	187	165	509.70±2.21	BDL	BDL
8 HP	7.13±0.03	27.6	280	6.1	1.3	148	134	1226.1±1.35	BDL	BDL
6 TW	7.47±0.02	30.1	279	6.6	0.6	148	138	972.36±0.53	BDL	BDL
22 TW	7.77±0.01	25.6	365	6.5	0.3	193	179	967.17±9.11	BDL	BDL
21 TW	6.49±1.37	27.8	254	6.2	1.1	135	130	560.77±10.73	BDL	BDL
7 TW	7.37±0.09	24.5	387	6.7	0.8	205	189	560.23±25.15	BDL	BDL
20 TW	7.23±0.07	28.6	467	6.4	0.3	248	243	473.20±16.49	BDL	BDL
19 TW	7.58±0.07	27.4	280	6.3	0.5	148	139	756.60±22.25	BDL	BDL
23 TW	7.72±0.11	28.4	245	6.9	0.6	183	178	366.03±17.21	BDL	BDL
I Tap	7.66±0.04	26.5	259	6.6	0.3	137	129	925.13±8.58	BDL	BDL
24 Tap	7.31±0.19	24.9	264	6.5	0.5	140	131	576.10±4.47	BDL	BDL
22 Tap	7.44±0.17	26.7	492	5.8	1.2	261	254	765.13±31.57	BDL	BDL
25 Tap	7.40±0.20	25.8	267	5.6	1.4	195	187	486.97±5.89	BDL	BDL
12 Tap	7.57±0.12	26.3	487	5.6	1.4	258	253	763.77±30.65	BDL	BDL
15 Tap	7.53±0.08	27.8	412	5.2	1.1	218	210	830.90±7.96	BDL	BDL
19 Tap	7.28±0.13	26.7	379	6.1	0.7	201	197	835.37±10.81	BDL	BDL
28 Tap	7.28±0.10	29.8	273	6.4	0.8	145	137	855.50±11.59	BDL	BDL
17 Tap	7.26±0.04	27.5	376	6.4	1.3	199	187	772.37±15.34	BDL	BDL
11 Tap	7.51±0.11	24.9	287	6.8	0.5	152	145	877.50±14.77	BDL	BDL
23 Tap	7.37±0.03	26.8	297	6.6	1.4	157	151	679.40±3.44	BDL	BDL
30 Tap	7.26±0.01	25.6	201	5.9	1.3	107	101	921.50±2.12	BDL	BDL
14 Tap	6.95±0.14	29.8	189	5.6	1.2	100	95	592.93±2.09	BDL	BDL
16 Tap	7.58±0.03	28.7	398	5.9	1.3	211	117	586.97±3.95	BDL	BDL
8 Tap	7.30±0.07	26.8	289	5.5	1.2	153	145	1135.77±14.17	BDL	BDL
5 Tap	6.92±0.05	27.4	359	5.7	0.9	190	178	487.97±4.14	BDL	BDL
6 Tap	7.37±0.04	24.8	290	6.3	0.7	154	149	568.30±18.60	BDL	BDL
7 Tap	6.85±0.02	26.1	328	6.1	0.9	174	169	636.43±12.01	BDL	BDL
10 Tap	7.75±0.06	25.3	284	6.5	1.1	151	145	434.87±3.75	BDL	BDL
21 Tap	7.64±0.01	25.5	192	6.3	1.3	102	98	460.13±29.86	BDL	BDL
26 Tap	7.65±0.06	24.6	279	6.7	1.6	148	138	730.13±1.67	BDL	BDL
27 Tap	7.60±0.07	27.6	293	5.7	1.4	155	146	742.43±7.18	BDL	BDL
29 Tap	7.35±0.03	28.8	267	5.9	1.5	142	137	844.40±20.58	BDL	BDL
2 Tap	7.74±0.02	25.4	310	6.1	1.3	164	157	733.37±5.05	BDL	BDL
9 Tap	6.95±0.06	26.3	330	6.8	1.4	175	165	956.20±19.45	BDL	BDL
3 Tap	6.42±0.22	26.6	430	6.3	1.2	228	219	1379.27±8.62	BDL	BDL
4 Tap	7.63±0.05	28.4	327	6.8	1.3	173	164	473.90±12.17	BDL	BDL
34 Tap	7.34±0.03	28.3	343	5.6	0.7	182	177	729.37±7.79	BDL	BDL
20 Tap	7.45±0.03	25.4	456	5.8	0.3	242	239	392.50±4.46	BDL	BDL
13 Tap	7.66±0.03	26.4	245	6.3	0.7	130	123	831.73±9.26	BDL	BDL
18 Tap	7.55±0.09	27.8	294	5.2	1.1	156	147	749.60±8.09	BDL	BDL

is due to the dissolved salts of Ca^{2+} and Mg^{2+} which percolate through the earth's crust. Higher content of these salts restricts the use of water for domestic, agricultural and industrial purposes.

3.5. BOD

BOD value is a parameter to evaluate the strength of waste in the water samples. The very low values of BOD are indicative of the good condition of the water. All the tap, tube well, and hand pump water samples were found to be within the permissible range (Fig. 4d). All the samples were found to have the BOD values between nil to 5.0 which is the prescribed limit by IS: 10500. The higher the BOD value, the more quickly oxygen is depleted and less oxygen is available for the aquatic life which suffocates them and ultimately leads to their death.

3.6. DO

Like BOD, the content of dissolved oxygen displays the organic pollution associated with it. The limits prescribed for DO is 4-6 mg/L. The water samples of the study area had the DO value in the range of 5 to 7.1 mg/L (Fig. 4e). 57% of samples were found to have the DO values greater than 6 which is beyond the prescribed limit by IS: 10500. The DO values indicate the modification due to aerobic/anaerobic mechanisms. Very low or high DO values can disturb the aquatic and human life. In addition to this, water with very high DO values facilitates corrosion of the water pipelines which restricts the smooth supply of water for domestic purposes.

3.6.1. Electrical Conductivity (EC)

The EC parameterizes the extent to which electricity can pass through the water. 61% water samples collected for this report were
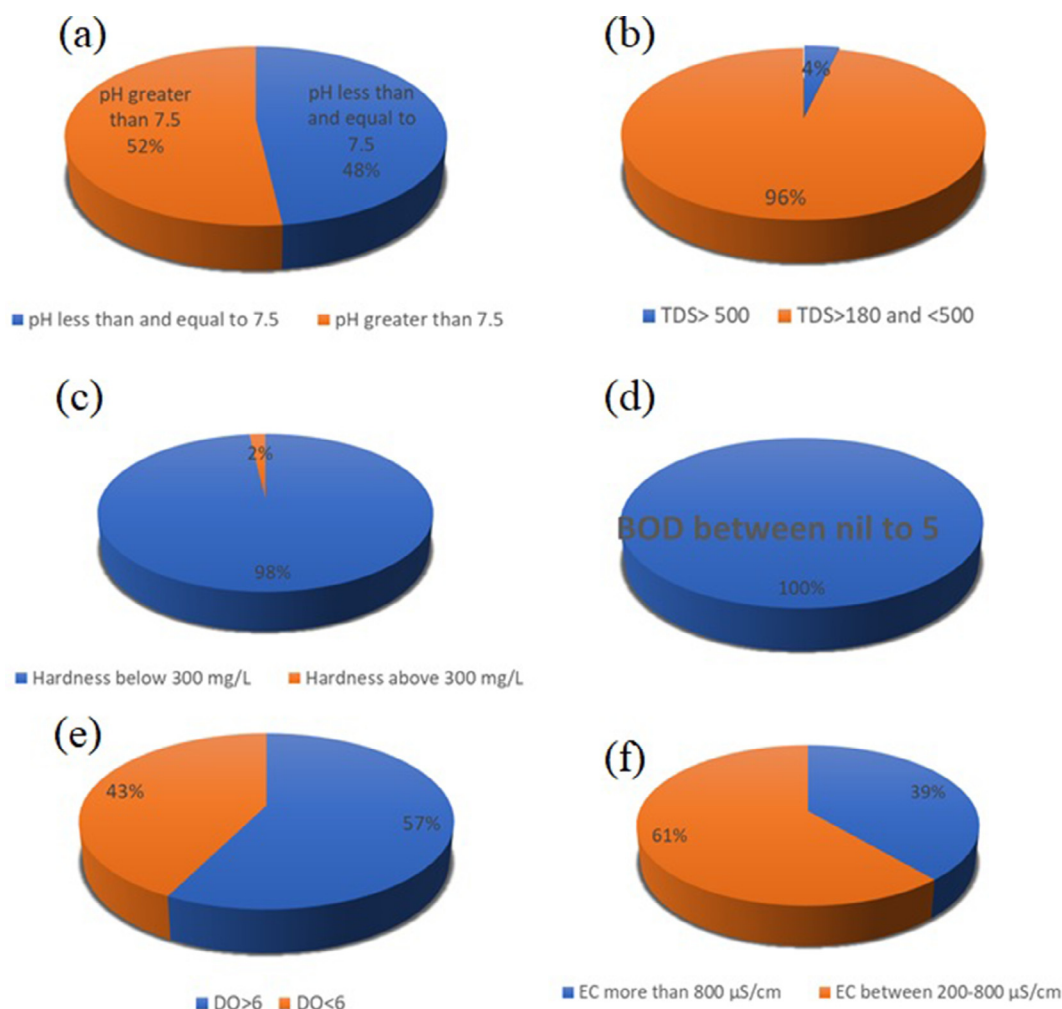
Fig. 4. Percentage of the samples having different (a) pH (b) TDS (c) Hardness (d) BOD (e) DO and (f) EC values.

found to be within the range of 200-800 μS/cm (Fig. 4f). 39 % of samples were found to have the EC values above 800 μS/cm. The EC values were found to fall between 243.86 and 1545.00 μS/cm. No permissible limits are suggested by WHO (2011) and BIS (2012) for EC. Leakage from the nearby dumping zones could be one of the sources of contamination resulting into higher EC values and consequentially increased salinity and mineral content.

3.6.2. ES and HCH levels

All the 54 water samples were found to have levels of emerging contaminants ES and HCH below the detection limits. The GC-MS spectrogram of the ES and HCH standards are shown in Fig. 5 (a and b). The spectrogram of sample 17Tap is shown in Fig. 5c. No peaks corresponding to characteristic retentions time of the target pesticide could be observed in any of the water samples which signified the presence of the target below the detection limit. The levels of ES and HCH being below detection limit indicated that the initiatives by Central and State Government seem to be creating sensitivity among the public, including among the farmers.

To summarize, some of the parameters such as colour, odour, temperature, pH and BOD were well within the prescribed limits for all the water samples. However, some of the physio-chemical parameters i.e. TDS, EC, DO and TH which are directly related to water quality, were above the limits specified by the BIS. The leachate from the nearby dumping areas could be responsible for the enrichment of groundwater of Chandigarh with contaminants pushing the parameters beyond the

prescribed limits. However, the water supplied for domestic purpose is treated before transmission and so it is safe for drinking. It is advised to treat the underground water from hand pumps before drinking. Some of the areas surrounding Chandigarh are heavily polluted by domestic, industrial, agricultural and construction waste which is manifested in the higher physiochemical parameters of the water samples from regions such as the Mullanpur and Dhanas region. It is recommended that the potential of microbial and radiological material can be explored for the treatment of water.

It is recommended that the potential of microbial and radiological material can be explored for the treatment of water. The studies done so far are limited to a period of six months only and may vary depending on seasons. The outcomes of this study can help in planning of remedial measures, management and establishment of system for regular assessment of the groundwater quality to save the public health.

4. Conclusion

An analysis of 54 samples from drinking and underground water of Chandigarh and nearby region was carried for the presence of emerging contaminants ES, HCH and the assessment of water quality. The results from this study indicated the levels of pesticides ES and HCH, below the limit of detection in drinking and groundwater samples of Chandigarh and nearby regions. The use of Integrated Pest Management (IPM) techniques such as light traps, bonfires, trap crops are being encouraged as
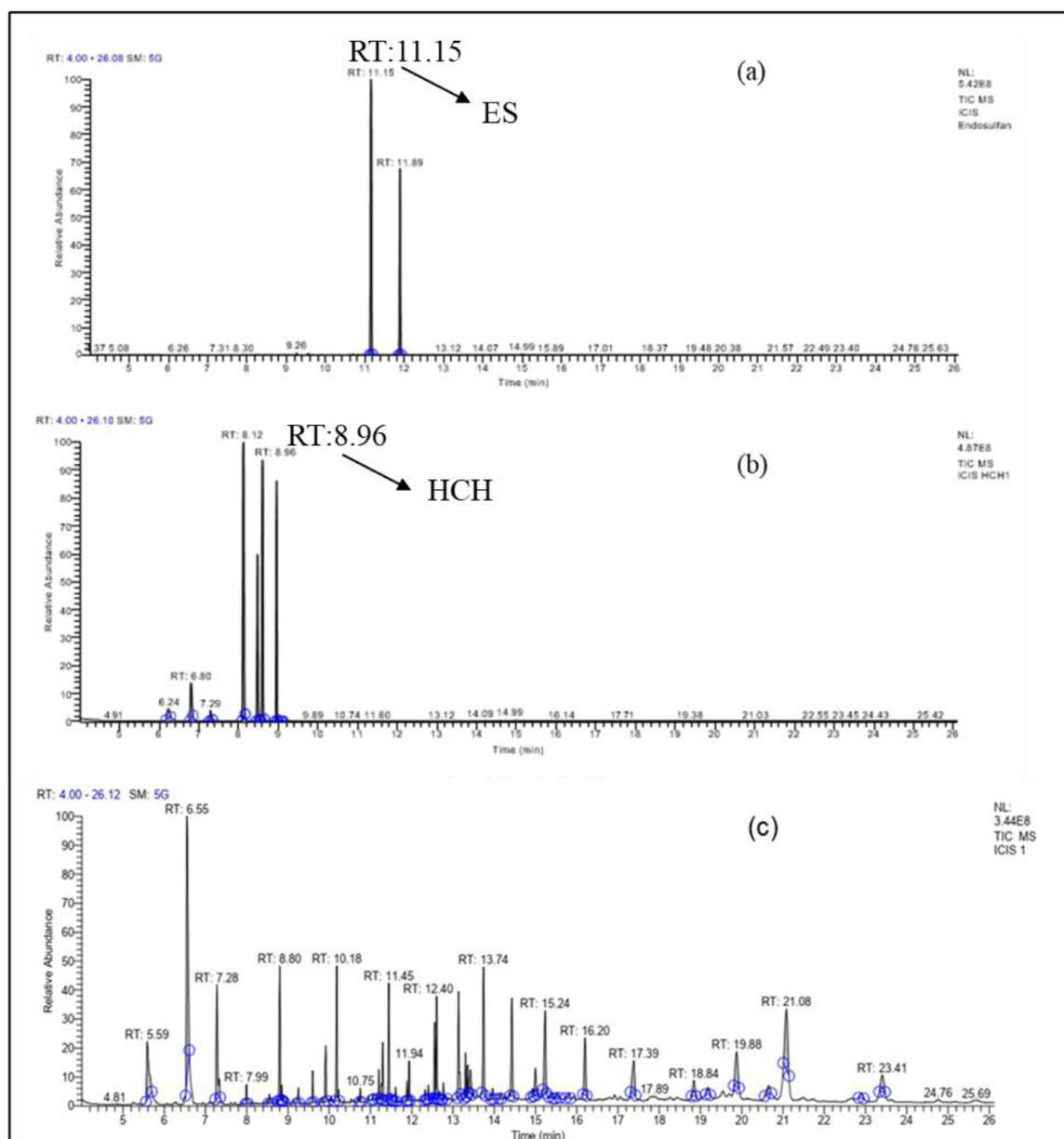
Fig. 5. Chromatogram of a standard reference sample of (a) ES, (b) HCH and (c) water sample 17Tap.

opposed to the use of pesticides. The use of bio-pesticides is being promoted by the government at special subsidized and loans for farmers. Training courses in self-protection, use of masks, use of spray pumps and measures for the disposal of pesticide containers are being propagated among the farmers. All these efforts and initiatives by various government agencies seem to be producing results. In our view, some preventive steps will be highly useful for finding solutions to the water problem will be highly useful. For example, the treatment of domestic sewage water and subsequent utilization of treated sewage water for irrigation of public parks will not only prevent pollution of water bodies but also reduce the demand for fresh water in the irrigation sector. The enforcement of Government policy and regulations for the safe disposal of effluents from industries is an important step. The Government should enforce 'the polluter pays' principle as a deterrent to illegal discharge of industrial effluents. Cleaning of rivers, lakes and other water bodies can also prevent water pollution.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envadv.2020.100002.

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