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Assessing the risk of landfill leachate on the groundwater quality of Chandigarh

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Abstract

Aim: Unscientific dumping of municipal solid waste (MSW) is still prevalent in the developing world, leading to adverse environmental and human health consequences. This study was conducted to assess the groundwater contamination due to leachate from the MSW dumping site in Chandigarh.

Methodology: Leachate and groundwater samples from different sources were collected for two sampling periods from the vicinity of dumping site within a radius of 3 km. Collected samples were analyzed for physico-chemical parameters, heavy metals and microbiological examination.

Results: The result showed high load of organic and inorganic contaminants in leachate as it had a higher COD value (10008 mgl^{-1} and 18280 mg l^{-1}) whereas ammoniacal nitrogen (NH_4^+-N) levels were 2389 mg l^{-1} and 5796 mg l^{-1} for two sampling periods. The concentration of Cu and Zn were highest amongst all the analyzed heavy metals in leachate samples. Almost all parameters in groundwater samples exceeded the BIS and WHO standard limits, which showed high contamination of groundwater surrounding the dumping site.

Interpretation: Higher concentrations of COD and NH_4^+-N in most groundwater samples indicates percolation of landfill leachate into the groundwater aquifer, leading to its contamination. Groundwater samples collected near the dumping sites of lower depth have higher levels of pollutants than the samples collected from higher depth.

Key words: Contamination, Groundwater, Landfill, Leachate, Risk assessment, Solid waste

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Introduction

Population growth and urbanization have increased the consumption of resources in the past few years and solid waste generation has become an unavoidable by-product of this growth. It has been reported that the population living in Indian cities generates around 48 million tons of municipal solid waste (MSW) and by the year 2047, it will rise to 250 million tons (Sharholy *et al.,* 2007). In India, solid waste is disposed in an unrestricted and non-systematic way (Vijayalakshmi and Abraham, 2017), resulting in adverse ecological impacts. Improper landfill construction without an integrated impact assessment raises a severe threat to the environment as well as human health (Chaudhary *et al.,* 2021). The major environmental problems associated with dumping sites/unsanitary landfill sites are the production of leachate and emission of greenhouse gases such as methane and carbondioxide, which is mainly attributed to high rate of waste degradation due to the presence of organic fraction. Moreover, landfill sites without bottom liners generate leachate that can enter unconfined groundwater aquifers and surface water bodies, making them unfit for various purposes, including domestic use (Fatta *et al.,* 1999; Longe and Balogun, 2010; Gautam *et al.,* 2011), potentially endangering the health of those living in vicinity.

The vulnerability of water sources (surface and groundwater) to leachate pollution highly depends on factors like type of dumping site, waste composition, susceptibility of an area, leachate characteristics, depth and flow of water table, etc. (Al-Khadi, 2006; Saidu, 2011; Singh *et al.,* 2009). Additionally, its chemical properties are determined by waste composition, landfill age, oxygen availability, meteorological factors and hydrogeological conditions (Przydatek, 2021). Leachate comprised of various complex organic (degradable) and inorganic (non-degradable) compounds, including humic substances, various salts, ammoniacal nitrogen, other nitrogenous compounds, heavy metals and microbes (Kjeldsen et al., 2002; Stollenwerk and Colman, 2003; Wiszniowski *et al.,* 2006; Mor *et al.,* 2006). Leachate causes a threat to the surrounding environment by physical, chemical and microbiological processes due to which toxic materials transfer its pollutants to the nearby waterbodies (Naveen *et al.,* 2017). Subsequently, these toxic pollutants during monsoon season show high percolation, disturb the groundwater table, and ultimately harm the local population living around. Additionally, the pollutants released from the landfill sites strongly affect the soil structure, which further deteriorates the growth of plants and microorganisms. Hence, landfill sites are the major sources of environmental risk due to leachate generation and its transportation through waste (Gworek *et al.,* 2016). The effect of leachate generated from landfills on the surrounding environment had been assessed in various scientific studies (Christensen *et al.,* 1998; Tatsi and Zouboulis, 2002; Mor *et al.,* 2006; Rana *et al.,* 2015, 2018; Lopez *et al.,* 2008).

In the current study, the impact of landfill leachate on the surrounding groundwater quality was investigated from the Dadumajra dumping site at Chandigarh, India. Physico-chemical parameters, heavy metals, and microbiological analysis was carried out in the collected leachate and groundwater samples to determine the potential risk to ground water quality near the dumping site. The study also examined the impact of different depths and distances of landfills from different groundwater sources (bore well and hand pump) and discussed remedial measures to prevent environmental risk. In addition, the study aimed to provide guidelines for the development and implementation of leachate treatment processes to limit the negative environmental effects.

Materials and Methods

Study area and information of dumping site: The study was conducted in Chandigarh, which is spread across an area of 114 km^2 and is located in the north-western region of India. The dumping site is located on the outskirts of the city near a rural area known as Dadumajra, a seasonal stream Patiala Ki Rao flows near the site (Fig. 1). The waste dumping site is 30-year old, spread around 42 acres without any leachate collection and gas extraction system. This dumping site receives over 350 tonnes per day of MSW from different sources like city's residential, commercial, and institutional areas. The waste comprised 52% of organic fraction and 21% of inorganic fraction of the total generated waste of Chandigarh. Most of the recyclables or combustible fraction of waste is either picked up by the informal workers or is processed in the Refuse Derived Plant. The residential and agricultural areas are present in the vicinity of the dumping site. The population of this area is highly dependent on the groundwater for domestic and irrigation purposes.

The water is drawn through available hand pumps, government wells, or bore wells. There are several hand pumps that can be spotted around the Dadumajra dumping site. However, most of them are either closed by Municipal authorities due to poor water quality or are non-functional for human consumption. Keeping this in view Municipal Corporation has installed two government wells at a depth of around 1200 ft. to supply water to the residents, which are located within 1 km of the dumping site. However, many functional hand pumps were observed surrounding the disposal site and groundwater samples were drawn from all available sources to assess contamination.

Collection of leachate and groundwater samples: To study the leachate percolation effect on surrounding ground water resources, the leachate and groundwater samples were collected from the adjacent areas of the dumpsite and examined for various physico-chemical parameters. Since no leachate collection facility is present near the waste dumpsite, leachate was collected randomly from leachate pools in the low-lying areas of the disposal site and around the waste piles during June-2011 and June-2012. These were later methodically mixed to get a representative grab sample. Three replicates of the extract were considered for the laboratory analysis of the samples. For analysis, 14 groundwater samples were collected for two sampling periods, 1 and 2, covering a radius of 3 km from the dumping site. At the time of first sampling period, the water table depth in shallow aquifers usually ranged from 2.79 m to 3.13 m, while at the second sampling period it was reported to be 2.32 m to 2.68 m (CGWB,2016). The location of hand pumps, boreholes, tube wells, submersible pumps, and sites was geo-coordinated with the help of a GPS (Global Positioning Satellite) system (Model: Garmin Montana 650). The information regarding age and depth of the sources of different areas were gathered simultaneously from the local residing population as detailed in Table 1. As indicated in Fig. 1, the maximum samples were collected from the southern and western parts, keeping in view the rivulet's flow, which suggests that the leachate flow would be more towards this side. Post collection, the samples were stored in ice-boxes and immediately transferred to laboratory for analysis.

Laboratory Analysis: Leachate and groundwater samples were stored in refrigerator at 4ºC and analyzed for physico-chemical parameters following the standard methods of APHA (2012). The pH, and electrical conductivity were estimated with a pH meter and conductivity meter, respectively. Total Dissolved Solids of the samples were calculated by the United States Salinity Laboratory Staff (1954) formula. Chemical Oxygen Demand was analyzed using reflux titrimetry. Calcium, Chloride, Total Alkalinity, Carbonate, Bicarbonate, Total Hardness were analyzed by titrimetric method. Phosphate, Ammoniacal Nitrogen, Sulphate and Nitrate were analyzed by spectrophotometer while Sodium and Potassium ions were analyzed using Flame Photometry. Fluoride ion was measured by SPADNS method. Heavy metals like cadmium, chromium, copper, lead, nickel and zinc were analyzed with Atomic Absorption Spectroscopy at International Testing Laboratory, Panchkula and Punjab Agriculture University, Ludhiana. The MPN (Most Probable Number) method was used to estimate total coliforms by inoculating the samples in different dilutions of Mackonkey broth. After inoculation, the incubation process was carried out for 48 hrs. The total coliforms were identified by variation in the color due to the production of acid and gases in the medium. Water samples can be categorized into four classes based on counts coliform. Microbiological examination was performed at the Department of Community Medicine and School of Public Health, Post Graduate Institute of Medical Education and Research (PGIMER), Chandigarh.

Statistical Analysis: The results obtained were tabulated and statistically assessed with SPSS (Statistical Package for the Social Science) package and later compared with the prescribed Standards of Bureau of Indian Standards (2012) and World Health Organization (2017). For data analysis, correlation analysis was performed in order to determine the degree of association among different variables.

Risk Assessment Conceptual Model: A robust conceptual model was developed for the risk assessment study to assess the risk of leachate percolation on the surrounding groundwater sources. The model has different stages, including historical information of the disposal site and current practices, type of solid waste dumped, monitoring of leachate and groundwater quality, evaluating risks, potential impacts, and the need for appropriate risk management measures. The present study was planned and conducted based on these different stages.

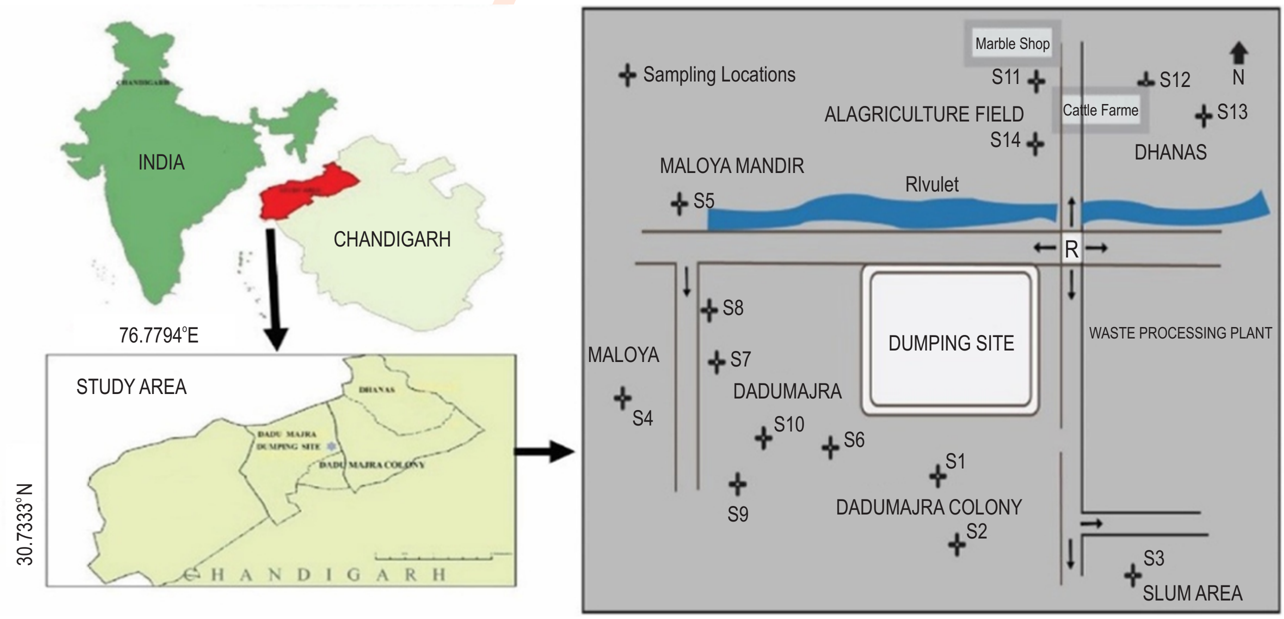

Fig. 1: Location of groundwater sampling at waste dumping site in Chandigarh, India.

Results and Discussion

The physico-chemical characteristics of leachate generally varies with the solid waste composition dumped and the age of the landfill (Fatta *et al.,* 1999; Tricys, 2002). The pH values of the leachate samples of two sampling sites were 9.36 and 6.95,indicating alkaline nature, which was due to high degredation of primary organic content producing ammonia and carbonic acid which further increases the level of pH. The pH value in leachate not only relies on the acid levels present in the leachate but also on the CO_2 pressure existing in the landfill gas, which in turn contact through the leachate (Banar *et al.,* 2006). Moreover, the methanogenic phase at the landfill site converts volatile fatty acids into CH_4 and CO_2, resulting in alkaline pH (Kanmani and Gandhimathi, 2013). The leachate alkalinity reveals the age of the dumping site (Jorstad *et al.,* 2004). This is typically noticed at landfills with disposal for last 10 years (El-Fadel *et al.,* 2002). The alkaline pH of leachate from Chandigarh, Panchkula and SAS Nagar area was also discussed by Mor *et al.* (2018) during pre-monsoon and post-monsoon season. In pre monsoon, the pH for three landfill sites was found to be 7.7, 7 and 6.7 while in post monsoon the pH was as 7.13, 6.6 and 6.5. Gomes *et al.* (2016) demonstrated that alkaline leachate contain several toxic metals such as household batteries waste, adding toxic elements like cadmium, nickel and chromium in landfill leachate (Mor *et al.,* 2018; Xu-Dan *et al.,* 2015). Leachate samples were found with higher values of EC (36982 and 48200 μScm^{-1}) and TDS (30068 and 34692 mg l^{-1}), indicating the presence of dissolved salts (Table 2) and various types of waste which is being dumped on the landfill site.

A high level of pH, EC and TDS were reported around the landfill sites. Amina *et al.* (2004) assessed the landfill leachate at Alexandria, Virginia dumpsite and reported the EC and TDS values as high as 41,637 μScm^{-1} and 30,083 mg l^{-1}, respectively. The Cl^- and F^- ions in the leachate samples were 2034.3 mg l^{-1} and 80 mg l^{-1}. A high NO_3^- (159 mg l^{-1}) concentration was also observed in the leachate. The concentration of NH_4^+ was 2389 mg l^{-1} and 5796 mg l^{-1}. High COD in leachate (10008 mg l^{-1} and 18280 mg l^{-1}) indicates high amount of organic material (Kaur *et al.,* 2016). El-Salam and Abu-Zuid (2015) reported COD values with an average of 15,629 mg l^{-1}. In the present study, a high concentration of NH_4^+-N (2389 mg l^{-1} and 5796 mg l^{-1}) was also observed in the leachate, which can be accredited to the degradation of biodegradable waste commonly due to fertilizers used in the agriculture field in the nearby areas (Mor *et al.,* 2006). The concentration of cations was found higher than the concentration of anions. The order of cation was noticed as Ca^+>Na^+>K^+>Mg^+ whereas anions SO_4^{2-}>Cl^->F^->PO_4^{3-}. Heavy metals (Cd, Cr, Cu, Ni, Pb and Zn) concentration was also analyzed and it was observed that Cu (4.3 ppm and 2.8 ppm) and Zn (7.01ppm and 7.1ppm) showed the highest value amongst all the studied heavy metals. Pb, Cd, Cr and Ni were found comparatively in lower concentrations indicating the disposal of hazardous wastes such as metal scraps, electronic items, medicines, paints, soiled litter, etc., at dumping site. Additionally, the high concentrations of characteristics of heavy metals at dumping areas could be due to solubility of metals (Kulikowska and Klimiuk, 2008).

Groundwater around the waste dumping site is used for various domestic as well as drinking purposes. Therefore, this becomes important to analyze groundwater quality. Groundwater samples were collected within the radius of 3 km around the dumping sites. During first sampling, the pH values of collected groundwater samples ranged from 6.8 to 7.8,with an average value of 7.24. However, during second sampling, the pH values ranged from 7.2-7.7 with an average value of 7.5. As per BIS standards, the collected groundwater samples showed pH within the desirable range of 6.5-8.5. Landfill leachate may raise the pH of drinking water, resulting in the formation of trihalomethane, a poisonous chemical to humans (Kumar *et al.,* 2010). EC values

Table 1: Details of sampling locations for groundwater collection, Chandigarh

Sample number	Locations	Geo-Co-ordinates	Types	Age (Years)	Depth (Feet)
S1	Jewellers DMC	N30 45.309 E76 43.565	HP*	30	40
S2	Mandir, D.M.C	N30 45.220 E76 44.120	HP	25	45
S3	Slum Area, 25	N30 45.219 E76 44.122	HP	1	25
S4	Carwashing, Maloya	N30 45.409 E76 43.250	TW*	1	100
S5	Mandir, Maloya	N30 45.454 E76 43.415	HP	1	70
S6	Khumar Colony, Dadumajra	N30 46.003 E76 45.088	HP	20	25
S7	Bakery near lake, Dadumajra	N30 45.288 E76 43.494	HP	1	100
S8	Pump, Dadumajra	N30 45.310 E76 43.466	TW	25	1200
S9	House, Dadumajra	N30 45.278 E76 44.002	SP*	12	57
S10	Wheat Mill, Dadumajra	N30 45.279 E76 44.017	HP	12	60
S11	Fodder shop, Dhanas	N30 46.003 E76 45.088	HP	8	60
S12	Milk Colony, Dhanas	N30 45.453 E76 44.495	HP	12	55
S13	House 329, Dhanas	N30 44.099 E76 47.381	HP	10	70
S14	Tubewell, Marble shop near Dhanas	N30 45.381 E76 44.385	TW	3	100

*HP- Handpump; SP-Submersible Pump; TW-Tubewell

Table 2: Composition of leachate collected from Dadumajra disposal site in Chandigarh

Parameters*	Sampling 1	Sampling 2
pH	9.36	6.95
EC	36982	48200
TDS	30068	34692
NH_4^+	2389	5796
NO_3^-	159	110
PO_4^{3-}	50.14	65.5
SO_4^{2-}	1798.6	4834
TH	13863	16377
Ca^{2+}	4902.3	5609
Mg^{2+}	392	572
TA	6260	10350
HCO_3^-	6260	10350
CO_3^{2-}	ND	ND
COD	10008	18280
Cl^-	1049.6	1383
F^-	69	80
Na^+	1892.7	2210
K^+	675	960
Cr	ND	0.026
Cu	4.3	2.8
Ni	ND	ND
Zn	7.01	7.1
Cd	ND	ND
Pb	0.09	0.06

* Except pH and EC, all values are in mg l^{-1} ND- Not Detected

during both sampling periods were found in the range of 390 μmhos cm^{-1} -1861 μmhoscm^{-1} and 526 μmhos cm^{-1} -1742 μmhos cm^{-1} respectively, in the samples (Fig. 2). Probably due to the presence of high level ionic species originating from nearby man made activities (Zereg *et al.,* 2018). TDS was noticed in the range of 249 -1191 mg l^{-1} and 362-1080 mg l^{-1} during the first and second sampling period, which was recorded higher than the WHO and BIS standards, *i.e.,* 500 mg l^{-1}. As per US salinity standards, groundwater samples fall under medium to high saline range category. Almost 50% of the samples resulted in high TDS values during both samplings, as presented in Fig. 2. The high values of TDS in majority of samples indicated percolation of leachate comprising the presence of dissolved salts with high concentrations. High concentration of dissolved salts in drinking water affects the palatability of water and may induce various other physiological reactions. High EC and TDS values of groundwater inferred the effect of local land fill sites and it could also be due to the geological nature of the studied area (Singh *et al.,* 2008). Total hardness of water depicts the total concentration of ions (Ca^+ and Mg^+) in the water.

The total hardness concentration exceeded the desirable limit of 500 mg l^{-1} as per BIS (2012) and 100 mg l^{-1} as per WHO (2017) in all the samples, except sample S8 (Fig. 3). The concentration of total hardness was noticed highest (459 mg l^{-1}) during the first and second (404 mg l^{-1}) sampling period. According to Durfor and Beckor's (1964) classification, the collected groundwater samples fall under 'Hard' and 'Very Hard' categories. Further, Ca^{2+} ions ranged from 36.8-100.8 mg l^{-1} and 44-117mg l^{-1} during both sampling periods in the collected groundwater samples (Fig. 3). Al-Sabahi *et al.* (2009) reported elevated levels of Ca^{2+} (396 mg l^{-1}) in the groundwater samples collected from the surrounding areas of a landfill in Yemen. The Mg^{2+} ion concentration ranged from 10.8-50.6 mg l^{-1} during the first sampling period, while during the second sampling period, concentration ranged from 12 -46 mg l^{-1}, respectively.

Sample S12 resulted in higher concentration of Mg^{2+} ions than the desirable limit of 30 mg l^{-1} as per BIS (2012). Total Alkalinity values in the collected samples ranged from 256-524 mg l^{-1} and 298-520 mg l^{-1} during both samplings. TA values in most samples exceeded the desirable limits of BIS (2012). The CO_3^- hardness was not observed in groundwater samples, while HCO_3^- hardness ranged from 294-521 mg l^{-1}. It has been reported that CO_2 gas produced during degradation of municipal solid waste within unlined disposal sites can be the source of high bicarbonates in groundwater (Pan *et al.*, 2019). Chloride ion is considered as a conservative element that is not affected by other biochemical processes. Hence, it is mainly considered a tracer element for determining contamination due to leachate (Fatta *et al.,* 1999; Castaneda *et al.,* 2012). In groundwater samples, Cl^- ions varied from 1.87-114.2 mg l^{-1} and 2.3 -95.6 mg l^{-1} in the collected water samples. In addition, many studies showed that K^+ ions can also be considered as a tracer isotope to assess water contamination due to leachate (Mor *et al.,* 2006; Castaneda *et al.,* 2012). The levels of K^+ ions ranged from 0.8 - 11.2 mg l^{-1} and 0.5 -17 mg l^{-1} in the samples (Fig. 2). The concentration of NO_3^- ranged from below detection limit to 28.7 mg l^{-1} during the first sampling period, while during the second sampling period, the values varied from 1.3 - 14 mg l^{-1}, which were found lower than the permissible limit (45 mg l^{-1}) of BIS (2012). However, WHO has set the prescribed limit of 10 mg l^{-1} for NO_3^- and in comparison to that, five locations were found to contain high levels of NO_3^- (Fig. 4).

In groundwater, there is a high level of NO_3^- is due to various sources, like soil leaching, fertilizer leaching, animal waste and irrigation water (Raju *et al.,* 2009). NO_3^- is considered a highly oxidized form of nitrogen compound, produced during aerobic decomposition of organic (degradable) compounds as the end product and is usually found in different water sources near the vicinity of dumping sites (Akinbile and Yusoff, 2011). NH_4^+-N values ranged from 0.1-1.68 mg l^{-1} during the first sampling period in groundwater samples which were observed above the permissible limit, while the second sampling did not show NH_4^+-N. The presence of organic pollutants in leachate indicated the presence of ammoniacal nitrogen. Naveen *et al.* (2017) reported the high concentration of ammoniacal nitrogen (2593 mg l^{-1}) in

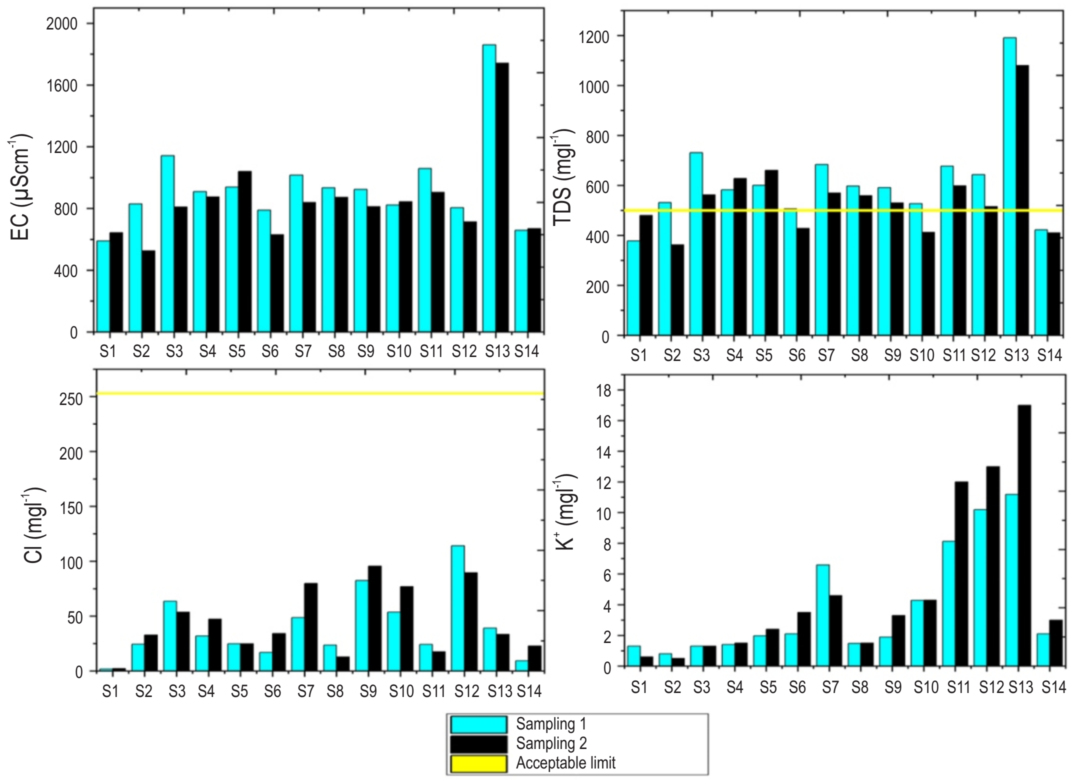

Fig. 2: Variation in EC, TDS, Cl^- and K^+ during different sampling campaigns in groundwater near the disposal site in Chandigarh.

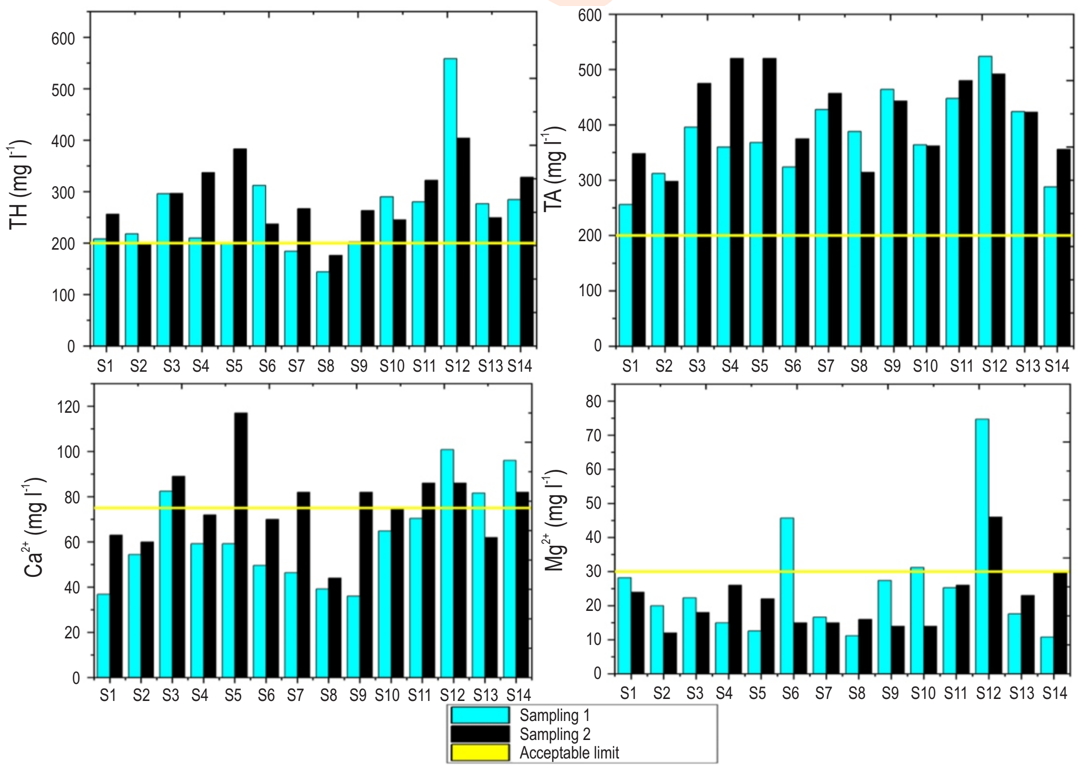

Fig. 3: Variation in TH, TA, Ca^{2+} and Mg^{2+} during different sampling campaigns in groundwater near the disposal site in Chandigarh.

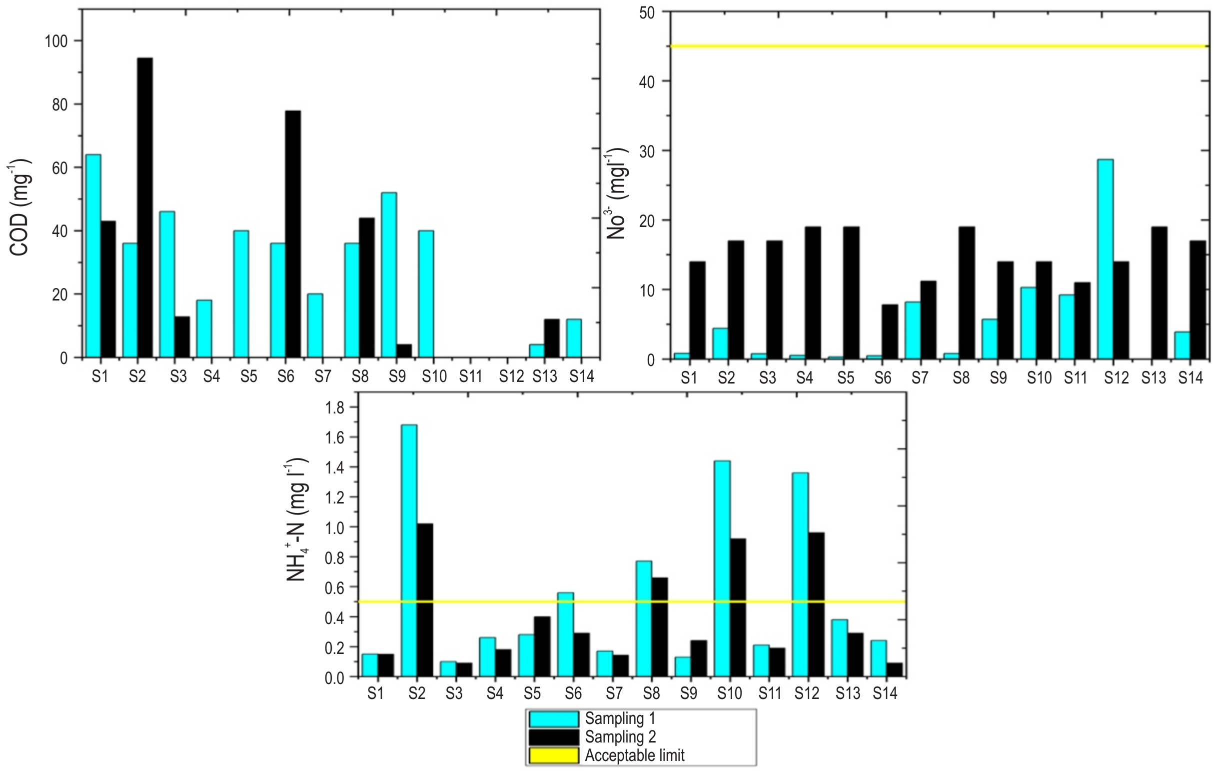

Fig.4: Variation in COD, NO_3^- and NH_4-N during different sampling campaigns in groundwater near the disposal site in Chandigarh.

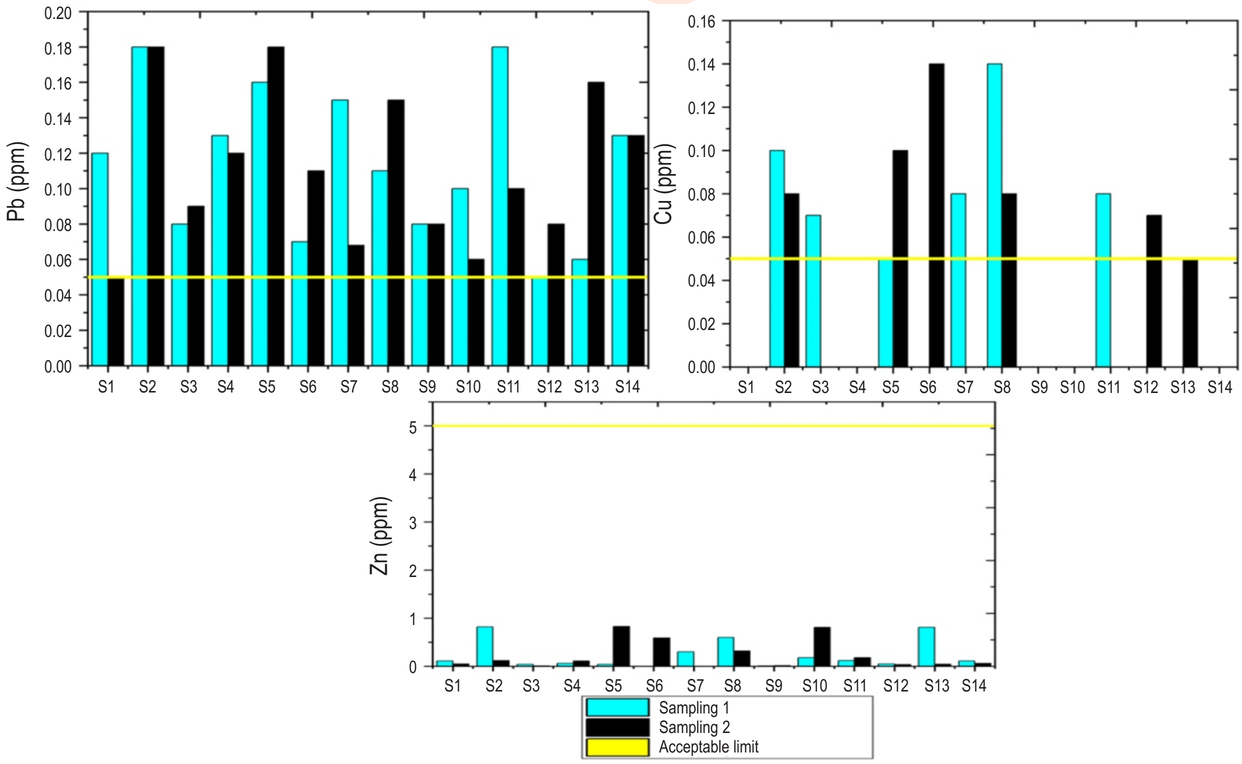

Fig. 5: Variation in Pb, Zn and Cu during different sampling campaigns in groundwater near the disposal site in Chandigarh.

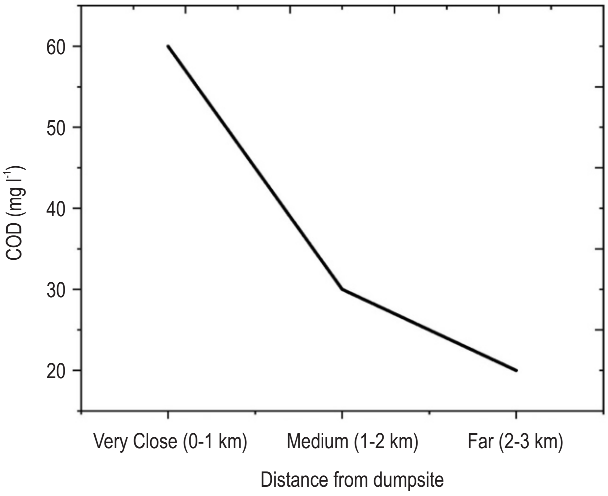

Fig. 6: Variation of COD with increasing distance from the dumping site.

Table 3: Microbiological quality of groundwater near waste disposal site

S.No.	MPN	As per MaCrady's Table
S1	1/100	S
S2	3/100	S
S3	0/100	S
S4	101/100	US
S5	3/100	S
S6	35/100	US
S7	24/100	US
S8	0/100	S
S9	3/100	S
S10	3/100	S
S11	0/100	S
S12	0/100	S
S13	3/100	S
S14	0/100	S

*S:Satisfactory, US: Unsatisfactory

Table 4: Variation in the chemical parameters at various depths (feet) in groundwater extraction sources (Handpumps, Tube wells and Submersible pumps).

Parameters	1-30	30-60	60-90	90-120	Above 1000
COD	**55.35**	27.8	41.9	15.7	29.6
Nh_4^+	0.26	**0.71**	**0.5**	0.22	0.69
Cl^-	**67.2**	**53.5**	30.2	38.7	18.1

urban municipal landfill leachate and 0.5 mg l^{-1} in pond water and open well of Bangalore city. No guidelines for ammonia in drinking water has been given by WHO (2017), while BIS (2012) has set the acceptable level of 0.5 mg l^{-1}, according to which most of the samples were found above this limit. A higher level of COD (> 70 mg l^{-1}) in groundwater samples was found in the areas closer to dumping site. High COD content of groundwater clearly indicated the presence of organic pollutants (Mor *et al.,* 2018; Kaur *et al.,* 2016; Samadder, 2017). However, the concentration of COD becomes untraceable as distance increases from the dumping site (Fig. 5 and 6). COD one of the critical components in the simulation of leachate percolation into the groundwater (Bagheri *et al.,* 2017). Further, Na^+, SO_4^{2-}, F^- and PO_4^{3-} were observed well within the prescribed limits of WHO (2017) and BIS (2012). In leachate, heavy metals play an essential role in determining groundwater contamination.

The presence of heavy metals in leachate implies that it is in an intermediate stage (Mor *et al.,* 2018). Among various heavy metals analyzed in the groundwater samples, Cd and Cr were found below detectable limit. However, Cu content was found above the desirable limit in most samples ranging from 0-0.14 ppm during both sampling periods. (Fig. 5). Cu content in groundwater can be from the leaching effect of dumping sites (Kanmani and Gandhimathi, 2013).The concentration of Pb was also found above the desirable limit of 0.05 ppm in most groundwater samples. The average value of Pb in all groundwater samples varied from 0.05-0.18 ppm and 0.06-0.18 ppm (Fig. 5). The concentration of Zn was reported to be higher. Still, it was well within the acceptable limit of 5 ppm, which may be due to Zn containing waste such as fertilizers, automobiles, industrial effluent and landfill leachate (Singh *et al.,* 2008; Kurakalva *et al.,* 2016; Choudhury *et al.,* 2021). As shown in Fig. 5, the Zn content in groundwater samples ranged from 0-0.81 ppm and BDL-0.083 ppm. In previous studies, Boateng *et al.* (2019) reported high level of Pb, Fe, and Cd in well water due to landfill percolation. Similarly, Vongdala *et al.* (2019) reported high levels of heavy metals in groundwater samples that bordered municipal solid waste. Indicating leaching out of heavy metals from the landfill waste, total coliforms were tested in groundwater samples following the MPN method. Out of 14 sampling locations, three sites S4, S6 and S7 showed the presence of coliforms in groundwater samples (Table 3). S4 and S6 samples were in close vicinity of the dumping site where handpump depth was shallow (25ft.). The presence of coliforms in groundwater samples again confirm leachate percolation to shallow aquifers releasing poisonous compounds that contaminate water sources (Kaushik *et al.,* 2018).

The results were found coherent with previously conducted studies (Chetna *et al.,* 2006; Malan *et al.,* 2020). The extent of groundwater contamination with leachate percolation is

Table 5: Variation in chemical parameters concerning the age of various groundwater extraction sources (Handpumps, Tube wells and Submersible pumps).

Parameters	1-5 years	5-15 years	20-30 years
COD	24.9	11.16	56.2
NH_4^+	0.219	0.58	0.66
Cl^-	43.96	64.52	18.17

influenced by numerous factors such as leachate composition, contiguity of water source, age and depth of groundwater sources, etc. In this study, the degree of contamination of groundwater sources was related to the age, distance and depth of the source by taking key parameters like NH_4^+, K^+, Cl^-, COD into consideration which are the main tracer of contamination through leachate. Tables 4 and 5 shows variation in different species concentrations at different depths. It was noticed that a high level of COD was fount at lowest depth of 0 – 30 ft whereas at 30-60 ft. and 60-90 ft, high concentrations of NH_4^+, K^+, Cl^- ions clearly showed leachate infiltration into the aquifer. In addition, the concentration of these species decreased as depth increased due dilution of leachate (Fig. 6). Comparable results have been reported by Naveen *et al*. (2017) for MSW landfill at Karnatka and Mor et al. (2018) for the dumping site of Jalandhar, Punjab. Based on the results, it can be concluded that leachate percolation significantly contaminates groundwater sources close to dumping site at lower depth. An attempt was also made to study the effect of age on water quality. High contamination was reported in old hand pumps/ submersibles/ supply wells. Sampling revealed a higher range of COD, K^+, Cl^- and NH_4^+ in the samples that were collected from older pumps/wells, *i.e.,* 20-30 years and 5-15 years old, showing that the aquifer was affected by the percolation of leachate as the age of dumpsite was also 29 years old. It has been observed that a close relationship exists in pollutant contamination with distance, depth and age of water source due to the well developed methanogenic conditions. This also showed the variation in the concentration of ionic species and inorganic pollutants. As the depth increases the concentration of ionic species decreases and concentration of inorganic pollutants increases. The study results were found coherent to the previously conducted studies.

Correlation analysis was used to estimate the relationship amongst different variables. A positive correlation coefficient (r) indicates that the level of individual variable increases with the increase in the level of other variables and *vice versa*. In contrast, a negative correlation indicates that the level of individual variable increases with decrease in the level of other variables. The observations of correlation analysis suggest that some parameters have a reasonable correlation with each other, indicating their close association. It was observed that EC is significantly correlated with TDS (0.984**) and K^+ (0.578**) at a significant level of 0.01 and 0.05, respectively. TDS was found to have a strong positive correlation with NO_3^- and K^+. NO_3^- was found to be significantly and positively correlated with TH (0.761**) and Mg^{2+} (0.745**) at a significant level of 0.01, while K^+ was reported to be positively correlated to EC, TDS, TH and Mg^{2+}. TH was also found to be highly associated with Ca^{2+}, Mg^{2+}, K^+, SO_4^{2-}, PO_4^{3-}, and Cl^-, which showed the exact source of pollutants. Further, Na^+ was found positively correlated to TA (0.773**) while K^+ was reported to be positively correlated to EC, TDS, TH and Mg^{2+}. COD was found negatively correlated to Ca^{2+} (-0.634*), TA (-0.651*) and K^+ (-0.550*) at a significance level of 0.05. The results of the correlation analysis were found coherent with the previously conducted studies (Mor *et al.,* 2006; Srivastava *et al.,* 2008; Aboyeji *et al.,* 2016; Negi *et al.,* 2020).

Overall, the study results indicated that the aquifer is not suitable for domestic use for the population living in the proximity of Dadumajra dumpsite. The exceedingly high levels of physico-chemical parameters including Total Coliforms and heavy metals in the groundwater samples, indicate significant threat to the health of the consumers. In addition, the level of contamination in groundwater sources owing to the percolation of leachate directly correlates with factors like depth, distance, and age of water sources.

Therefore, the findings of this study confirm that the unscientific disposal site located in Dadumajra, Chandigarh, poses a threat to the surrounding groundwater resources. Hence, there is a need to take immediate remedial measures such as (i) closing the existing dumpsite, as it has already reached its capacity; (ii) converting unscientific dumpsite into sanitary landfill with the provision of leachate collection and treatment system; (iii) if sufficient funds are available with the municipality, remediation of the site and aquifer can be done; (iv) sanitary landfill site should be constructed and made in operation with a provision of leachate collection and treatment facility; to prevent further infiltration of leachate into the groundwater.

There is an urgent need to formulate a corrective action plan that aims to prevent further contamination of the aquifer and prevent leachate percolation. Some of the possible options to avoid risks associated with the contaminated site and ensure suitable water quality may include (I) closing the existing dumpsite, as it has already reached its capacity; (ii) converting unscientific dumpsite into sanitary landfill with the provision of leachate collection and treatment system; (iii) close all the hand pumps and tube wells in the close proximity of the dumping site, even those located at deeper depth, as there are possible chances of contamination; (iv) if sufficient funds are available with the municipality, remediation of the site and aquifer can be done; (v) sanitary landfill site should be constructed and made in operation with a provision of leachate collection and treatment facility.

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Add-on Information

Authors' contribution: K. Kaur: Work plan, groundwater and leachate water sampling, laboratory analysis, manuscript writing; **S. Mor:** Conceptualization, editing, writing, review, formal analysis; **N. Vig:** Review and editing; **R. Khaiwal:** Conceptualization, editing, writing, review, formal analysis.

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