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Research Article

Quality analysis of groundwater and surface water bodies around the selected brick kilns in Fatehgarh Sahib and Rupnagar Districts in Punjab, India

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Abstract

Brick production is a business that benefits many people, such as providing building materials, employment, and interest to the business owners. However, it has been associated with many adverse impacts various components of ecosystem.Thepresent studyaimed to determine the impact of isolated brick kilns onthe pollution levelof water bodies in Fatehgarh Sahib and Rupnagar Districts of Punjab, India. Physicochemical and microbiological parameters of water were evaluated. The results revealed that the isolated brick kilns partially impacted the water bodies, as the concentration of heavy metals waspresent in surface water near the study area. Parameters such as electrical conductivity (EC), Turbidity, total dissolved solids (TDS), Chloride (Cl), alkalinity and chemical oxygen demand (COD) estimated for surface water samples showed high contamination levels, except for pH, which was acidic (6.2) for surface water. The groundwater was alkaline with pH estimated to be 7.6. The alkalinity and COD levels of groundwater were 693.3 mg/l and 12.4,respectively, as the peak values, and both values were beyond the permissible limits for drinking water. Total coliforms were present in all samples at low health risk (13/15), except two surface water ponds, which showed a health risk. One-third of groundwater was highly contaminated by *Escherichia coli*, whereas only one of the twelve samples was contaminated with*E.coli.* The changes of all estimated water parameters in groundwater with distance did not follow any spatial pattern. They could partially be attributed to the lithology of the soil and prominent agricultural activities in the region. The WQI was highly influenced by heavy metals, notably arsenic (As) from both lithologic and brick kilns' origins and lead (Pb) from burning fuels in the brick kilns.

Keywords: Coliforms, Contamination, Physicochemical, Water pollution, Water Quality Index (WQI)

INTRODUCTION

Bricks are an ancient building material dating back to 7000 BCE(Murmu and Patel, 2018), and todate, the world production averages1.5 trillion bricks per year (Schmidt, 2013; Weyant *et al.*, 2014). The China's brick production, along with that of India and other South Asian countries, consumes more than 75% of the world's production (Rehman *et al.*, 2020).The high demand for bricks as an important material in the construction sector has led to serious environmental degradation (Murmu and Patel, 2018), affecting living and non-living substances (Aniyikaiye *et al.*, 2021), and the most affected ecosystem is the atmosphere, in which the pollutants associated mainly with the poor-quality combustibles used to fire thebricks, generate a variety of pollutants, including CO_2 (major pollutant), SO_2 and NO_x(Koroneos and Dompros, 2007). The air emissions from brick kilns have been associated with the technology used to fire the bricks(Schmidt, 2013). Notably, the smoke and ash produced from coal combustion spread over the cultivable land, making it infertile,reducing crop yield(Khan *et al.*, 2019). Brick kilns are also the major consumers of biomass, making them the potential contributorsto deforestation and greenhouse gas emissions (Tahir and Rafique, 2009).

Recently,the inclusion of municipal waste in the brickmaking process, in line with minimizing the depletion of natural resources (e.g., clay and sand), recycling and reuse of municipal solid waste has also impacted the environment and industrial workers. Indiscriminate dumping of solid waste such asincinerators' waste and sludge from different sources, notably pharmaceutical wastewater, urban sewage and the brewing industryforusing them in making construction material like bricks can also increase the emission of heavy metals and inorganic particles twenty times higher than natural clay(Rehman *et al.*, 2020). Generally, anthropogenic activities and associated consequences are highly negatively affecting water quality and are becoming a crucial issue for today and future human livesworldwide (Jin *et al.*, 2020). The intrusion of industrial effluents into the rivers changes the water quality parameters of the aquatic ecosystems, loweringavailable Dissolved Oxygen (DO) levels for aquatic inhabitants(Elkiran *et al.*, 2019).

Water pollution has been the potential cause of waterborne diseases for many decades, particularly in developing countries experiencing rapid industrial growth and facing environmental conservation challenges(Patil *et al.*, 2015; Kant Pareek *et al.*, 2020). Sometimes, waterborne pathogens are transmitted throughcontact with contaminated water from lakes, rivers, oceans,etc., during recreational activities(Griffiths, 2008). Water pollution varies with water characteristics of different seasons and natural processes such as temperature and precipitation, affecting human activities and the quality of water bodies (Barakat *et al.*, 2016).

It is, therefore, essential to continuously monitor water quality parameters, as they contribute significantly to water quality restoration by comparing the physicochemical observations with the standard guidelines (Khatri *et al.*, 2020). Brick kilns are among the prominent industrial activities that pollute water bodies and contribute significantly to air quality deterioration. The river bank,which usually contains huge clay deposits, the rivers themselves as water sources, and the distance from urban areas to the waterfronts are the potential factors considered for the establishment of brick kilns(Aniyikaiye *et al.*, 2021). Brick kilns produce a variety of wastes in the three states of matter. The waste, once produced, enters water bodies in the form of gases, particles and suspended particles, or by waste disposal near water bodies(Saha and Mostafa, 2021). Rainwater, in particular, transports waste as it washes out the sites and carries the rest of the materials to the rivers in the form of water flows in constructed channels or surface runoffs to rivers (Aniyikaiye *et al.*, 2021).

The other link betweenwater pollution and the brickmaking business is the habitation of brick workers; brick workers andtheir families set up their shelters atwork sites, which are usually agricultural lands, damp during the rice growing season. Basic hygiene and sanitation facilities, especially toilets and drinking water, are inadequate or even missing in the brick kiln sites (Daly *et al.*, 2020).Inaccessibility to quality or safe water is still a serious concern in many countries (Kelly *et al.*, 2020; Rahman *et al.*, 2023) due to both natural phenomena, e.g., hydrological, atmospheric, climatic, topographical, and lithological factors of the concerned area, and anthropogenic activities, e.g., industrial, and domestic waste disposal, irrigation, uses of agricultural fertilizers and pesticides (Uddin *et al.*, 2021; Zhang *et al.*, 2021).Different management tools were developed to achieve water quality requirements. The Water Quality Index (WQI) model is an effective toolin estimating water's potable quality.

Studying the environmental impact of a production facilityis an inevitable requisite as it helps to deal with the consequences of the production processes on the environment. In the case of brick kilns, not only the impact on the environment but also the health and safety of workers are serious issuesin the brickindustry, especially in developing countries where the technology of processing raw materials to produce dried or firedbricks is still primitive or artisanal, energy and labour intensive, even unprofitable for workers. In the Indian state of Punjab, there are a significant number of brick manufacturing units. Much of the research has been conducted to determine how brick kiln operations affect the water quality and assess various respiratory health risks of kiln workers related to workplace air exposure. The present work explored the environmental impact of the brick kilns on water bodies located nearby, as the air pollutants from the kilns' chimneys end up settling on the land and water bodies in the form of wet and dry deposition.

MATERIALS AND METHODS

Study area

The present study focused on the state of Punjab (Fig. 1),which is located in the northwestern part of India and has an estimated area of 50,362 km^2. Its geographical location extends from 73°53' to 76°56' east longitude and from 29°33' to 32°32' north latitude(Jyoti et al., 2021; Dabas et al., 2023) (Fig. 2).Termed the breadbasket of India, the state is divided into 22 districts

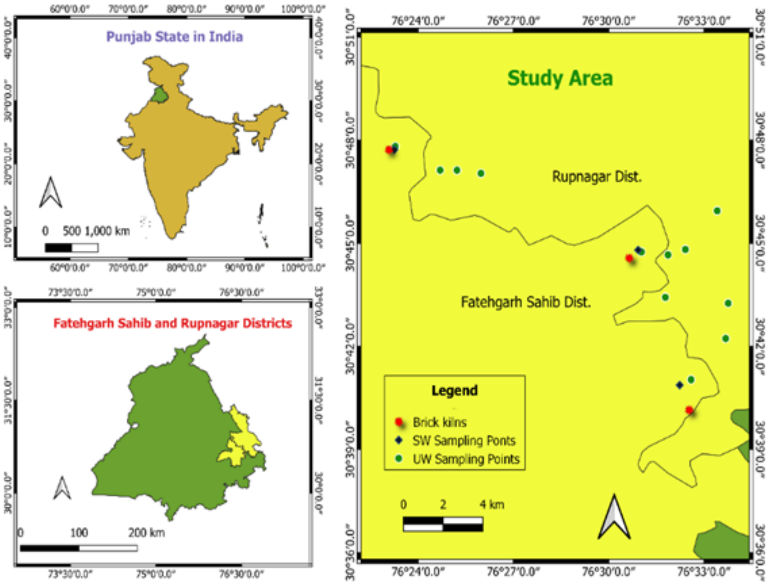


Fig.1.*Showing map of the study area in Fatehgarh Sahib and Rupnagar Districts of Punjab*

dominated by intensive agricultural activities that make the district one of the important producers of wheat and rice in the country (Dabas et al., 2023). In rural areas of the state, many village ponds serve for rainwater harvesting, livestock bathing and irrigation(Ansal et al., 2010). Due to the household wastewater discharges in the statevillage ponds, the later are rich in nutrients, which attract many species of migratory and local birds (Kaur et al., 2018).The state of Punjab is characterized by significant production of Bharat bricks (fired bricks), as about 2500 brick production units withmore than 2 lakh workersis a prominent non-agro-based industry in the state (Kainth, 2009).

To draft the study plan, a pilot survey was first conducted to locate the brick kilns on Google Earth. Then, the brick kiln locationsof interest were visited to verify their functionality and confirm the locationsfor study.To avoid the multifactorial influence of environmental pollution on water bodies, the sites of interestwere isolated kilns,randomly selected under the condition that they were located at least 10 km from the nearest other brick kilns, withthe mandatorypresence of a water body (wetland, river, ponds, etc.) within a radius of one kilometer from the kiln position. The brick kilnswere not located close to other factories with nearly similar pollutantsthat may influence the present research three sites were identified, and geographical coordinates for the same were recorded. Site A was located in SangolVillage (30°47'43.1"N 76°23'13.6"E),Site B, in Rupalher Village (30°40'52.2"N 76°32'28.0"E), and Site C, in Bhateri Village (30°44'54.7"N 76°30'59.9"E), all of them in Fatehgarh Sahib District.

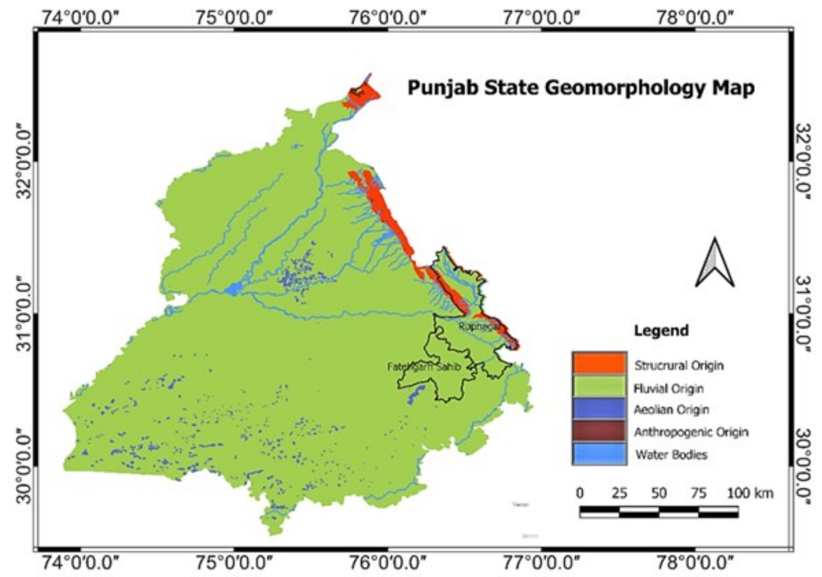


Fig. 2. *Geomorphological map of Punjab State*

The soil of Punjab State, as shown in Fig. 2, is dominated by an alluvium plain, grouped in five orders, namely Aridisols, Entisols, Inceptisols, Alfisols and Mollisols(Sehgal, 1974). With time, there is the development of argillicsoil,indescending order composed of SiO_2, Al_2O_3 and Fe_2O_3, and other compounds, including CaO, MgO, Na_2O, K_2O and H_2O, with some traces of free iron (Fe) and aluminium (Al) translocated from lower horizons to surface horizons(Tomar, 1987).A recent study on the chemical properties of the soil of Punjab, demonstrated that naturally, the aridisols are salty and calcareous, with calciumcarbonate ($CaCO_3$) content estimated to be 6%, whereas Entisols and Inceptisols had a $CaCO_3$ content estimated to 4.9% and 4.3%, respectively. The soil pH ranged between 7.4 and 7.8, showing the alkalinity nature of the alluvial soils (Dhaliwal *et al.*, 2022).

The soil in Punjab is a part of the Gangetic Plains of India, which was originallyformed from transported volcanic sediments. Thus naturally,theycontain high concentrations of Arsenic, Fluoride, Boron, Selenium and Manganese (Srivastava, 2020). Weathering of parent bed-rock with sulfide content and traces of heavy metals like copper, nickel, lead, and cobalt turn arsenic sulfides into arsenic trioxide, which is easily transported as dust or as a solute in water (Mandal andSuzuki, 2002). The arsenic-bearing minerals contaminating the unconsolidated sedimentary aquifers on the globe, and India in particular, include arsenopyrite (FeAsS), realgar (As_2S_2), orpiment (As_2S_3), and iron pyrites (FeS_2) (Jha andTripathi, 2021).

Water samples collection

Water samples were collected in December 2022, from the vicinity of three majorbrickyards, using domestic hand pumps and electric irrigation pumping stations. As shown inTable 1, five water samples were collected for each of the three selected sites, resulting in fifteen water samplescollected ina randomizedblock design. Water sampleswere collected in multiple stagesto separate samples for microbiological analysis and physicochemical analysis and to address specific treatment and testing requirements foreach category of analysis.

One-litre and five-litre capacity high-density polyethene containers were used to manually collect water samples for physicochemical and elemental analysis.The containers were washed with detergent and water, rinsed with deionized water, and sealed before being takenout for field water collection. The samples were transported to the laboratory within 3 to 4 hours and stored in a cool place for further analysis. No preservation chemical was used during the storage period.

For biological assays, water samples from three surface water (water ponds) locations and twelve groundwater pumping stations were collected in 2 ml Eppendorf tubes,which were pre-sterilized in an autoclave at 121°C and 15 psi for 1.5 hours, along with all the reagents. All petri dishes used for analysis were washed with detergent and sterilized at 150°C for 24 hours in a hot air oven. The samples were transported immediately to the biotechnology lab within one hour and refrigerated at 4°C for nearly another hourto set the petri plates in the Laminar airflow and prepare dilution solutions.

Table 1. Plan for water sample collection

Type of water source	Distance from kiln	Names given to the water samples		
		Site A	Site B	Site C
Surface water	0 - 1 km	ASW01	BSW01	CSW01
Ground water	0 - 1 km	AUW01	BUW01	CUW01
	1 - 2 km	AUW12	BUW12	CUW12
	2 - 3 km	AUW23	BUW23	CUW23
Control sample	~ 5 km	AUCS5	BUCS5	CUCS5

Physicochemical analysis of water quality

Standard methods of testing water and wastewater in the laboratory were followed (Table 2) to conduct all experiments on physicochemical properties.

Sample analysis for heavy metals

For heavy metal analysis, an indirect methodusing Scanning Electron Microscope (SEM) and Energy-

Table 2. Tested water parameters and their analytical methods

Sr. No.	Parameter	Methodology (Analytical Method)
A. Physicochemical Analysis		
1.	pH	pH Meter (LI-64 Model)
2.	EC	EC Meter
3.	Turbidity	Nephelometric Turbidimeter
4.	TDS	Gravimetric Method
5.	TSS	Gravimetric Method
6.	Alkalinity	Titrimetric Method
7.	Chloride	Argentometric Method
8.	COD	Closed Reflux Titrimetric Method
B. Microbiological Analysis		
9.	*Escherichiacoli*	Standard Plate Count Method (SPCM)
10.	Total coliform	Standard Plate Count Method (SPCM)
C. Elements		
11.	Heavy Metals	Indirect method using Energy Dispersive X-Ray Spectroscopy (EDS/EDX) Technique

Dispersive X-ray Spectroscopy (EDX or EDS) was adopted (Rajkovic et al., 2008).To obtain the residue in powder from water samples needed for EDS test, the water with a volume between three and five litres, depending on the quantity of total solids in the sample, was evaporated in a hot air oven for two to three hours. After evaporation of the water, the residue was collected, weighed, and stored in a labelled plastic package. The collected powder wasthen analyzed in a SEM, and EDX reports were generated, indicating the percentage of each chemical element in the samples analyzed (Qi et al., 2003).

Microbiological analysis

For determination of E. coli and total coliform, eosin-methylene blue-agar medium and tryptone-glucose-agar medium, respectively, were prepared (Anil and Arnab,2022), poured into the petri dishes and solidified in a Laminar airflow. The petri dishes were then stored at 4°C, waiting for inoculation of the sample solutions, which were diluted to varying strength with autoclaved 0.1% peptone saline solution. Once inoculation was complete, the petri dishes were incubated at 37°C for 24 hours, after which the counting process was performed, and observations were recorded. Estimating bacterial concentration (E. coli and total coliform) in the water samples was based on the following mathematical equation (Willey, 2009; Some *et al.,* 2021).

$$Total\ number\ of organisms\ per\ litre = \frac{N}{DF \times V} \qquad (1)$$

Where, N = Number of organisms (Countable colonies), V = Volume of sample (Actually equivalent to one drop or 100 µl or 0.1 ml), DF = Dilution Factor (10^{-1}, 10^{-2}, …, 10^{-5})

Data analysis

Descriptive statistics and correlation matrix were used to analyze the results. MS Excel was used to perform statistical operations on the data for better understanding and visualization. The water parameters were evaluated for their suitability as drinking water by comparing them with the water quality standards as prescribed in IS 10500: 2012, second revision. Finally, Weighted Arithmetic WQI was used to rank the suitability of the water sources (Kumar et al., 2016; Ayoub and El-Morsy, 2021).

RESULTS AND DISCUSSION

Fifteen water samples were collected from different locations around three isolated brick kilns. Three samples were of surface water and twelve samples were of ground water. The summary of the results with minimum, maximum, mean and standard deviations for the physicochemical and microbiological tests performed are presented in Table 3, whereas Table 4shows the rate at which the samples fit the drinking water requirement.

Table 3. Showing results for physicochemical and microbiological testing

Parameters	**Surface Water**				**Groundwater**				**Control sample**	**IS 10500: 2012 (2nd revision)**	
	Min	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**		**Acceptable limit**	**Permissible limit**
Electrical conductivity (µS/cm)	1080.0	2911.0	1783.3	986.50	445.0	942.0	633.0	185.71	512	300*	1500*
pH	5.7	6.8	6.2	0.55	7.0	8.3	7.6	0.49	8.07	6.5 - 8.5	No relaxation
Turbidity (NTU)	23.6	49.6	33.1	14.32	0.5	1.5	1	0.37	0.94	1	5
TDS (mg/l)	144.7	369.7	256.5	112.51	173.2	402.8	260.7	85.49	193.83	500	2000
Chloride(mg/l)	40.0	76.0	60.0	18.32	8.0	20.0	12.4	3.93	15.97	250	1000
Alkalinity	725.0	2035.0	1211.7	716.96	495.0	965.0	693.3	229.56	681.67	200	600
COD(mg of O_2/l)	36.8	43.2	40.5	3.33	8.0	17.6	12.4	2.92	11.7	-	10 *
Escheiricia. coli (CFU/100 ml)	$11x10^4$	$22x10^4$	183333.3	95393.9	0.0	$3 x10^4$	3333.3	0	0	Not detectable	No relaxation
Total coliform(CFU/100 ml)	$22 x10^5$	$295 x10^5$	$1175 x10^4$	16212033	$1x10^4$	$7 x10^5$	144444.4	52218.6	$2.7 x10^4$	Not detectable	No relaxation

Table 4. Number of tests complied and not complied to BIS permissible limits

Parameters	**Surface Water**		**Underground Water**	
	In range	**Out of range**	**In range**	**Out of range**
EC	2/3	1/3	12/12	0
pH	1/3	2/3	12/12	0
Turbidity	0	3/3	12/12	0
TDS	3/3	0	12/12	0
Chloride	3/3	0	12/12	0
Alkalinity	0	3/3	2/12	10/12
COD	0	3/3	4/12	8/12
Parameters	**Negative (-)**	**Positive (+)**	**Negative (-)**	**Positive (+)**
Escheiricia coli	0	3/3	11/12	1/12
Total coliform	0	3/3	0	12/12
WQI and Status	**Number**	**%**	**Number**	**%**
0-25 (Excellent)	-	0	6	50
26-50 (Good)	-	0	-	0
51-75 (Poor)	-	0	-	0
76-100 (Very poor)	-	0	3	25
>100 (Unfit for drinking)	3	100	3	25

Electrical conductivity (EC)

As can be seen from the observations in Table 3, the values of EC for all groundwater samples met the requirement of BIS fordrinking water, whereas the EC ofthe surface water samples was much higher than that of groundwater, and one of three surface water samples had an electrical conductivity beyond the permissible requirementsof BIS as summarized inTable 4.The average conductivity for surface water and groundwater was 1783.3 µS/cm and 633.0µS/cm, respectively. Since, EC is directly proportional to TDS (Udhayakumar *et al.*, 2016), the same correlation was seen in this study, where a weak positive correlation was observed between the two values (Table 6). In addition, it was observed from Fig. 3(a) that the EC was far higher for surface water (1080.0 and 2911.0µS/cm, minimum and maximum values, respectively) than for groundwater (445.0and 942.0µS/cm, minimum and maximum values respectively). Since EC is always proportional to the amount of solids dissolved (TDS) in the water, EC is indirectly an indicator of inorganic pollution load (Verma and Anju, 2018). Therefore, the dust and flyash from brick kilnchimneys increase inorganic pollution load in general, and heavy metal pollution in particular, of surface water, and simultaneously increasing the EC of the water. Acidity formation in water is a complex process involving different factors(Akpan *et al.*, 2021). The reason for thehigher mineral content in surface watermay be probably due to its openness, the air deposition of pollutants from the nearest brick kilns and other anthropogenic activities easily reach the surface water(SahaandMostafa, 2021), and in some cases, the surface water ponds were the dumping sites for different types of industrial and domestic waste (Singh, 2014; Kaur *et al.*, 2018).

pH

The pH valuesfor all groundwaters were in line with the BIS requirements of drinking water(Table 4), and only one of three surface water samples was within the permissible limit.The average pH values for surface water and groundwater were 6.2 and 7.6, respectively, as presented in Table 3. The variations inpH of surface waterandgroundwater arevisualized also from Fig. 3(b), which showsa lower pH of surface water (pH< 7, acidic) than thatof groundwater(pH>7, alkaline).The lower pH values of the surface waternear the brick kilns indicate the pollution of the water by heavy metals from the smokestack, which directly impacts land and water ponds surrounding the brick kilns (Dey and Dey, 2015, 2017).

Total dissolved solids (TDS)

The TDS content of both surface and groundwater samples met the requirements of BIS for drinking water, with average values of 256.5 mg/l and 260.7 mg/l, respectively. As it can be observed from Fig. 3(e), the TDS values fluctuated arbitrarily, and around brick manufacturing site B, the TDS content in groundwater was higher thanthe TDS content of the other sites.These values could be attributed to the intensive use of agricultural fertilizers in higher quantities.In fact, the brick business is not the only contributor to high EC and TDS values; the origin of these parameters can also be traced to the weathering of rocks, intensive use of fertilizers and groundwater pumping in thestudy area (Kaur *et al.*, 2017).

Turbidity

As summarized in Table 3 and Fig. 3(d),the turbidity values for collected samples met the BIS requirements

Table 5. Showing heavy metals tests' results of water samples

Metals	ASW01	AU-W01	AU-W12	AU-W23	AUCS5	BSW01	BUW01	BUW12	BUW23	BUCS5	CSW01	CUW01	CUW12	CUW23	CUCS5	Control sample	BIS Acceptable Limit	BIS Permissible limit
Cr	-	0.0529	0.0472	-	-	0.0680	-	-	-	-	-	-	-	-	-	-	0.05	NR
Mn	-	-	-	0.0518	-	-	-	-	-	-	0.0617	-	0.1094	-	-	-	0.10	NR
Fe	-	-	0.1652	-	0.0246	0.2720	-	-	0.0842	-	0.5557	-	-	0.1946	-	0.008	0.30	0.08*
Ni	3.1668	0.1588	-	-	-	-	-	-	-	-	2.0992	-	-	-	-	-	0.07	15
Cu	-	-	-	-	0.0492	-	-	0.0471	-	-	0.0617	-	-	-	-	0.016	0.05	
Zn	7.9803	0.1059	-	-	-	0.1360	-	0.0471	-	-	-	-	-	-	0.0229	0.008	5.00	
As	4.9402	1.4559	-	0.0259	-	0.3400	0.0460	-	-	-	2.0066	-	-	0.0486	0.0229	0.008	0.01	NR
Pb	9.8804	-	-	-	-	0.4080	-	-	-	-	-	-	0.0219	-	-	-	0.01	NR

*WHO limits at the absence of IS limits; NR: No Relaxation; All units are in mg/l;The coding (naming) of water samples is mentioned in Table 1.

of drinking water for all groundwater samples,while for surface water, they were well above the permissible standards for drinking water. The average values were 33.1 NTU and 1 NTU for surface water and groundwater samples, respectively. These turbidity values for the surface water could be due to the accumulation of particulate matter from ash (fuel burning), sand and excavated soil from the brick-making sites (Deyand Dey, 2015).

Chloride

Chloride levels in the samples complied with the BIS for surface water and groundwater samples, averaging 76.0mg/l and 12.4mg/l, respectively. Although the current chloride levels are acceptable, theprevious studies conducted in the region have shown that water sources at various places have been seriously impacted bythe unfortunatedisposal of solid waste, which could probably resultinhigher chloride concentrations in surface water (Singh *et al.*, 2015).

Alkalinity

The alkalinity of the water samples tested was within the acceptablelimits for only two groundwater samples, whereas it was above the permissible limits for the remaining surface water and groundwater samples.The observation fromFig. 3(f)indicates a minimal variation in the alkalinity values for bothsurface water andgroundwater, except for one case of surface water where the alkalinity was higher (2035.0 mg/l) compared to the other sampling points in the study area. The value observed in thisparticular case was comparable to the results observed in the industrial areas of Chandigarh city(Kaur and Malik, 2012), thereby indicating the influence of industrial activities on water quality.Thealkalinityof that particular sampling point also increased the average value for surface water (1211.7 mg/l), far above the estimated average for groundwater samples (693.3 mg/l), as indicated inTable 3.A high alkalinity value makes the water unpleasant and can show its potential to cause health issues (Bindra *et al.*, 2021).

Water characteristics can be influenced by soil interaction, so different water sources may differ in mineral content (Chopra and Krishan, 2014).Sincethe study area is located in the southern part of the Satlej River, where the adjacent districts of Fatehgarh Sahib and Rupnagar are dominated byhigh salinity and high alkalinity soil derivedfrom the bedrock in the region(Kumar *et al.*, 2007), this could also be account for the high alkalinity values observed in the present study.

Chemical Oxygen Demand COD

The average values for COD were estimated to be 40.5 mg/l and 12.4 mg/l for surface water and groundwater

Table 6. Correlation matrix of tested water parameters

	EC	**pH**	**Turbidity**	**TDS**	**Chroride**	**Alkalinity**	**COD**	**Cr**	**Mn**	**Fe**	**Ni**	**Cu**	**Zn**	**As**	**Pb**	***E. coli***	**Totalcoli**	*WQI*
EC	1.000																	
pH	**-0.835**	1.000																
Turbidity	**0.936**	**-0.825**	1.000															
TDS	0.537	-0.488	0.238	1.000														
Chloride	**0.848**	-0.729	**0.947**	0.131	1.000													
Alkalinity	**0.897**	-0.660	**0.833**	0.376	0.772	1.000												
COD	**0.769**	**-0.786**	**0.922**	0.026	**0.920**	0.631	1.000											
Cr	0.012	-0.253	0.128	-0.103	-0.042	-0.125	0.213	1.000										
Mn	-0.152	0.157	-0.009	-0.408	0.108	-0.155	0.116	-0.230	1.000									
Fe	0.102	-0.351	0.350	-0.339	0.475	0.011	0.639	0.228	0.209	1.000								
Ni	**0.834**	-0.647	**0.876**	0.150	**0.920**	**0.854**	**0.809**	-0.168	0.113	0.337	1.000							
Cu	0.024	-0.106	0.091	-0.050	0.298	-0.047	0.303	-0.244	0.144	0.453	0.249	1.000						
Zn	**0.905**	-0.607	**0.818**	0.394	0.711	**0.951**	0.586	-0.115	-0.130	-0.151	**0.820**	-0.134	1.000					
As	**0.869**	-0.709	**0.874**	0.228	**0.839**	**0.889**	**0.751**	0.001	-0.011	0.152	**0.947**	0.073	**0.896**	1.000				
Pb	**0.912**	-0.616	**0.829**	0.393	0.719	**0.951**	0.599	-0.105	-0.129	-0.140	**0.819**	-0.138	**1.000**	**0.892**	1.000			
E. Coli	0.565	-0.699	**0.764**	-0.027	**0.801**	0.325	**0.896**	0.325	0.136	**0.762**	0.575	0.307	0.258	0.482	0.276	1.000		
T. Coli	0.307	-0.531	0.458	0.027	0.346	0.018	0.540	0.645	-0.091	0.414	0.012	-0.070	0.006	0.046	0.032	0.732	1.000	
WQI	**0.920**	-0.665	**0.866**	0.343	**0.782**	**0.953**	0.670	-0.070	-0.089	-0.037	**0.886**	-0.065	**0.987**	**0.954**	**0.987**	0.358	0.038	1.000

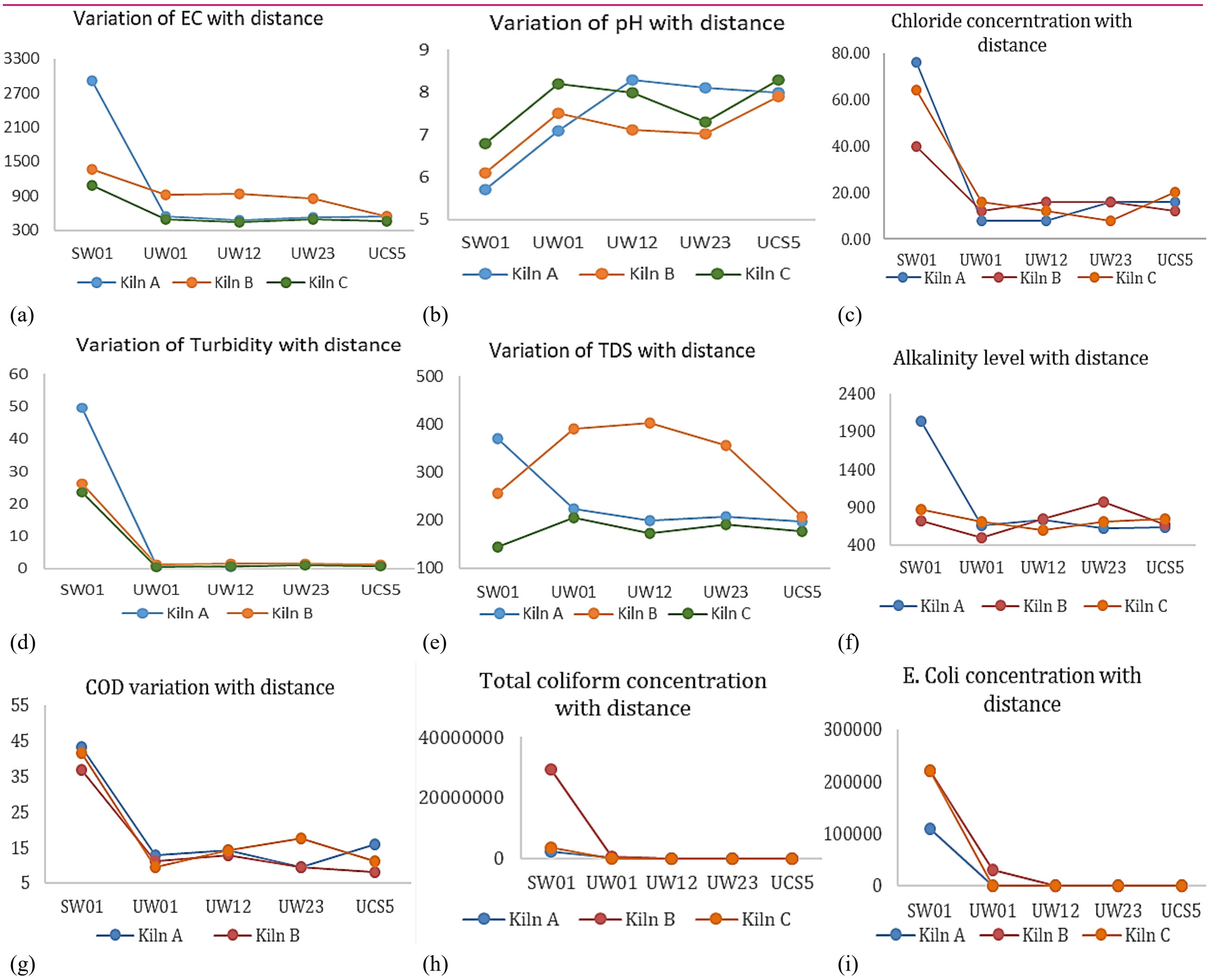


Fig.3. *Variation of water parameters with distance measured from brick kiln*

samples, respectively, which were higher than permissible limits. COD indicates the estimation of oxygen needed to decompose organic and inorganic materials in water (Singh and Paul, 2019), and the high COD values in surface water and their significant correlation with EC as well as turbidity (Table 6) in this study, showed the high concentration of oxidizable solid pollutants in surface water than in groundwater.

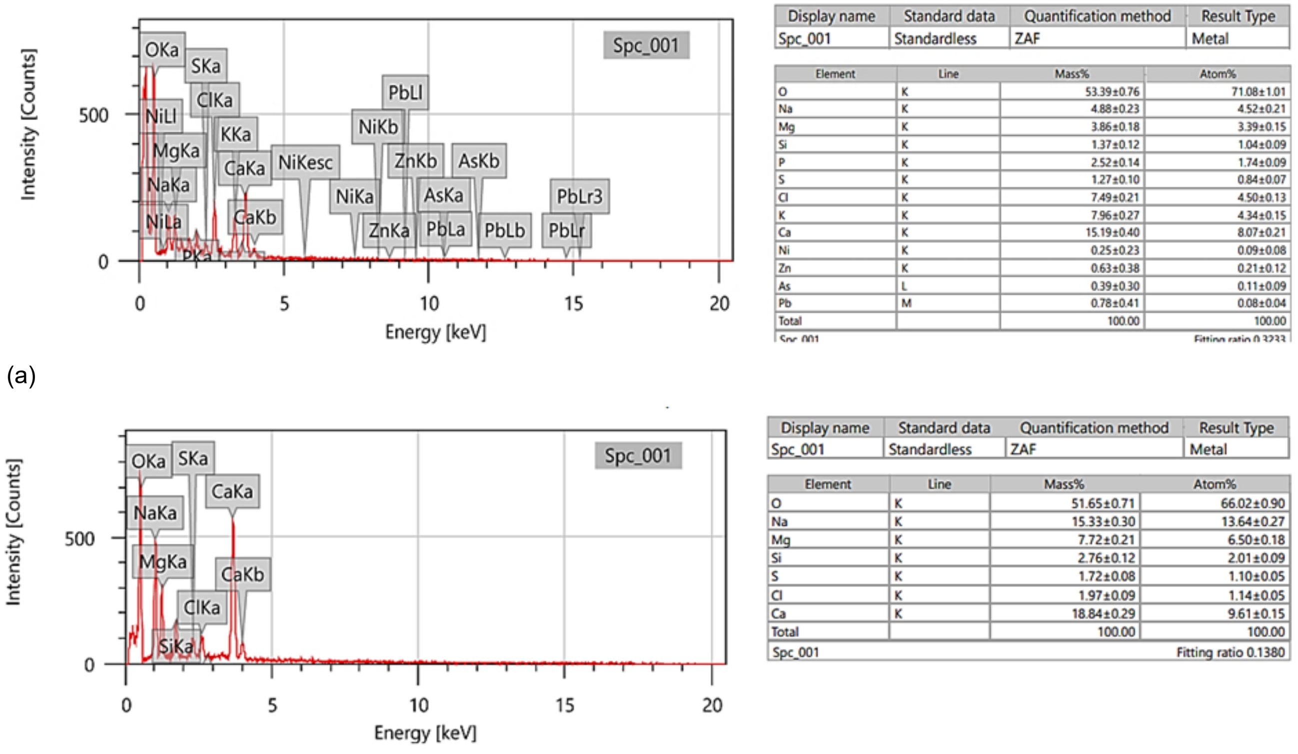
Moreover, only four out of twelvegroundwater samples metthe COD requirements for drinking water (10 mg/l). The high levels of COD in groundwater may be attributed to the percolation of organic materials down to the aquifer and the presence of microorganisms (coliform) in the water. In the present study, the COD values for surface water and groundwater were similar to those found in Chandigarh city, which indicates that the COD values originated from anthropogenic activities (Kaur and Malik, 2012). A recent research showed that many species of birds also live in and around the surface water (water ponds) in Barnala District of Punjab State (Kaur *et al.*, 2018).During the period in which this study was conducted, ducks were seen in the ponds visited,whichis a sign of microbiological activity and poor water quality. The disposal of various types of domestic and commercial waste in the ponds may lead to the entering and biomagnifications of contaminants in theaquatic food chain by affecting the COD levels in surface water.

Microbiology analysis results

The results from testing the water sample, showing the minimum, maximum and mean values forColony Formed Units (CFU)oftotal coliform and E. coliare presented in Table 3.Considering the water quality requirements for bacteriological safety, all the sampled water sources tested were unsafe for drinking water, as they were found positive for total coliforms. All the surface water samples were also found positive for E. coli, whereas one out of twelve groundwater samples was positive for E. coli (Table 4). The extent of contamination was greaterin surface water samples than in groundwater samples(Fig. 3(h)and Fig. 3(i)).

Table 7. Heavy metals concentration in groundwater in the Fatehgarh Sahib District, Punjab

Parameters	**Units**	**(Kumar *et al.*, 2020)**				**Present study**		
		Pre-monsoon		**Post-monsoon**		**Winter**		**Control sample**
		Range	**Average**	**Range**	**Average**	**Range**	**Average**	
Cr	µm/l	0.01-0.73	0.11	0.07–1.16	0.49	0-53.0	8.3	-
Mn		0.06-54.87	4.8	0–72.6	3.67	0-109.0	13.4	-
Fe		12.5-549	150	0–558.68	161.26	0-194.0	39.0	8
Co		0.01-0.6	0.11	0–0.4	0.07	-	-	-
Cu		0.28-67	4.22	0–80.62	3.22	0-49.2	8.0	16
Zn		12.8-833	139.9	0–540	29.02	0-105.9	14.6	8
As		0.23-18.4	4.16	0.02–9.55	1.26	0-1456	133	8
Se		0-145	14.46	0–71.12	6.06	-	-	-
Cd		0-5	0.14	0–1	0.11	-	-	-
Pb		0-1	0.14	0.08	0.13	0-28.9	1.6	-
U		1-105	28.53	23.13	13.09	-	-	-



(a)

Display name	Standard data	Quantification method	Result Type
Spc_001	Standardless	ZAF	Metal

Element	Line	Mass%	Atom%
O	K	53.39±0.76	71.08±1.01
Na	K	4.88±0.23	4.52±0.21
Mg	K	3.86±0.18	3.39±0.15
Si	K	1.37±0.12	1.04±0.09
P	K	2.52±0.14	1.74±0.09
S	K	1.27±0.10	0.84±0.07
Cl	K	7.49±0.21	4.50±0.13
K	K	7.96±0.27	4.34±0.15
Ca	K	15.19±0.40	8.07±0.21
Ni	K	0.25±0.23	0.09±0.08
Zn	K	0.63±0.38	0.21±0.12
As	L	0.39±0.30	0.11±0.09
Pb	M	0.78±0.41	0.08±0.04
Total		100.00	100.00
Spc_001			Fitting ratio 0.3233

(b)

Display name	Standard data	Quantification method	Result Type
Spc_001	Standardless	ZAF	Metal

Element	Line	Mass%	Atom%
O	K	51.65±0.71	66.02±0.90
Na	K	15.33±0.30	13.64±0.27
Mg	K	7.72±0.21	6.50±0.18
Si	K	2.76±0.12	2.01±0.09
S	K	1.72±0.08	1.10±0.05
Cl	K	1.97±0.09	1.14±0.05
Ca	K	18.84±0.29	9.61±0.15
Total		100.00	100.00
Spc_001			Fitting ratio 0.1380

Fig. 4. *EDX test results for the most (a) and least (b) polluted water samples collected from the area of study*

The presenceof *E. coli* andtotal coliforms werealso more significant for surface water than for groundwater, which is justified by the fact that there workers constantly settle in slums around brick kilns, where basic hygiene and sanitation facilities, especially toilets,are inadequate or even absent (Singh, 2014; Daly *et al.*, 2020),and a large number of birds livein water ponds in state of Punjab (Kaur *et al.*, 2018). In 2019, a study onthe bacteriological quality of groundwater revealed that more than 60% of groundwater sources in Punjab are affected by bacteriological pollution and are unfit for drinking due to leachate from landfills and more than 14% were contaminated with *E. coli*(Tiwari *et al.*, 2019). In Fatehgarh Sahib district, 50% of groundwater was contaminated by *E. coli* in 2019(Bindra *et al.*, 2021), and this situation could be due to the inadequate use or maintenance of toilets, despite the consistent efforts of the Government of India to improve the hygiene practices (VerKuilen *et al.*, 2023).

Heavy metals analysis results: As presented in Fig. 4, the EDX results showed the content of all metallic and non-metallic elements present in the water samples as the percentage of mass and percentage of atoms. In all the samples, Oxygen (O), Sodium (Na), Magnesium

Table 8. Average WQI values and their variation with sites

Site	Type of water	Average WQI	Status
A	Surface water	55103.2982	Unfit for drinking (WQI > 100)
	Ground water	300.3860	Unfit for drinking(WQI > 100)
B	Surface Water	13961.7413	Unfit for drinking(WQI > 100)
	Ground water	45.1484	Good (26 ≥ WQI ≥ 50)
C	Surface water	7640.0541	Unfit for drinking(WQI > 100)
	Ground water	88.3590	Very poor(76 ≥ WQI ≥ 100)

(Mg)and Calcium (Ca) were the major contents.The heavy metals were only present in surface water samples, and the groundwater sampled at less than the one -kilometer distance from the kiln contained aluminum content (1.68 mg/l) beyond the BIS permissible limits (0.2 mg/l). As shown in Table 5, the sample ASW01, a surface water sample collected between zero and one kilometer from brick kiln A, was highly contaminated with Nickel (Ni, 3.1668mg/l), Arsenic (As,4.9402 mg/l) and Lead (Pb,9.8804 mg/l), their concentration was far higher than the BIS permissible limits for drinking water, whereas Zinc (Zn) content was above acceptable limit, but below the permissible limit.The surface water sample CSW01 also containedNickel(Ni) andArsenic (As) beyond the permissible limits defined for drinking water, whereas Chromium (Cr) and Zinc (Zn) contents were below the permissible limits.

The accumulation of pollutants from the brick kilns to the nearby cultivable soil may reduce the soil fertility and theimpact may increase with the rise in the number of brick kilns in an area (Skinder *et al.*, 2014; Rajonee and Uddin, 2018). The emissions from brick kilns may adversely influence the respiratory system and impact the economy by reducing the agricultural crop productivity and richness of aquatic life, especially fish production (Jerin *et al.*, 2016). Plants can intercept and accumulate chemicals, making these contaminants a part of food chains (Marguí *et al.*, 2005).

The silt-clayey soil characteristics are also associated with high permeability(Kumar *et al.*, 2007; Verma *et al.*, 2021),therefore, it is easier for the contaminated surface water to percolate into groundwater aquifers. Recent studies conducted in the region have indicated that groundwater in the peripheral regionof Fatehgarh Sahib and Rupnagar districtsis contaminated with heavy metals like uranium(11-30 µm/l), arsenic (0.066-0.5 µm/l), Lead(0.003-0.5 µm/l) and chromium (0.022-0.5 µm/l)(Kumar *et al.*, 2020). From the data given in-Table 7, it is clear that As and Pb concentrations were higher in groundwater around brick kilns than the pollution in the control sample, as well as from other areas with anthropogenic activities. Another possibility for higher heavy metal content such as Zn could be ascribed to the use of fertilizers or the dumping of E-waste and industrial waste, raising the concentration of other heavy metals such as Cr, Al, Mg, Cu and Pb too (Ravindra and Mor, 2019).

Water Quality Index (WQI) for water sources

The Weighted Arithmetic WQI values of water sources were calculated, and the results showed that all the surface water wasin critical status (Unfit for drinking, WQI>100), whereas 50% of the groundwater sources were categorized as excellent (0 ≥ WQI ≥25), andpoor (51≥WQI≥ 75) and very poor (76 ≥ WQI ≥ 100) categories counted 25% of the groundwater sources each. Site A had the highest WQIindices for both surface and groundwater, as shown inTable 8. This is due to its location, which allows water contamination from different pollution hazards, as it is located near a highway, where small businesses also operate. As observed, one of the boreholes significantly increased the average value of the WQI for groundwater used indiscriminately as a source of irrigation and car washing.

The other observation was that the presence of heavy metals in water was approximately 98% contributing to the WQI values, notably the concentrations of arsenic (As) and lead (Pb) followed by nickel (Ni) and Zinc (Zn). This is because the concentrations of those heavy metals were found to be very high compared to the standard values. The observed value was almost 1000 times the standard value for some cases. This relationship was approved by the highly significant correlation of WQI with electrical conductivity and the concentration of heavy metals, i.e., As, Pb, Ni, and Zn, as evidenced from recordings in Table 6.

In a previous research, the Heavy metal Pollution Index (HPI) on groundwater in Chandigarh, Punjab, revealed that although the water sources had traces of heavy metals, they were within permissible limits (Ravindra and Mor, 2019). As the concentrations of heavy metals are not more significant in the areas where agriculture is the main anthropogenic activity (Bhatti *et al.*, 2016; Krishan *et al.*, 2021), the high WQI calculated for water sources around brick kilns in the present study, as well related to brick manufacturing business and other businesses that were being run around them. The sources of heavy metals and their impact on WQI could vary seasonally and were found to be significant during monsoon season (Singh *et al.*, 2017).

Conflict of interests

The authors declare that there is no competing interest.

Conclusion

The present study revealed that water sources around the brick kilns ishighly affected by the presence of the brickmaking business, as higher concentrations of heavy metals were present, and most of them were beyond the permissible limits defined by BIS for drinking water, compared to the areas where agricultural is only the influencing human activity. Water testing for heavy metals was successfully achieved by using EDS, and the latter may be an alternative method to AAS for testing heavy metals and the traces of other elements in water.

It isimportant to note that the brick kilns were not the only contributors since it was observed that the WQI of water was higher in surface water than in groundwater, as the water ponds were the dumping points also of solid waste from nearbyplaces and workers'habitationto or not to the brick making activity in the area. The WQI of water was highly influenced by heavy metals, notably from both lithologic origins and brick kilnsandPb from burning coal as fuel in the brick kilns.In addition, physicochemical parameters, i.e., alkalinity,COD and total coliform, were beyond the permissible limits defined by BIS for drinking water. The high alkalinity,as with many other physicochemical parameters, originates from lithologic sources of the area more than any anthropogenic activity. In fact, the values for different parameters for groundwater found in this research did not match any pattern in terms of varying with distance from the kilns. The differences exhibited were between surface water and groundwater. It is advised to partially replace coal with biomass as it may be an effective strategy to appease the harmful pollution to air, soil and water emitted from burning coal for firing the bricks.

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