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Exploring the intricate correlations among physicochemical parameters in the groundwater of Gadarsi village, nestled in the serene landscape of Kurukshetra, Haryana, India

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Abstract
All organisms depend on water—either surface water or groundwater—for their fundamental needs. Groundwater, in particular, serves as an essential alternative to surface water and is crucial for long-term water sustainability. To ensure its viability as a safe water source, a comprehensive evaluation of groundwater quality is necessary. This research aims to investigate the groundwater quality of Gadarsi village in Kurukshetra District, Haryana. The study was conducted by collecting 10 samples from different houses to evaluate the groundwater quality using physicochemical parameters during the post-monsoon season of 2022. Water quality parameters include temperature, pH, EC, total dissolved solids (TDS), turbidity, and heavy metals. Cadmium (Cd), Chromium (Cr), Copper (Cu), Zinc (Zn), Iron (Fe), and Lead (Pb) were analysed using standard methods. Results showed that the range of pH ranged from 7.2– 8.4,(8.06±0.4), temp 19.47-24.070C (22.14±1.10), TDS 528-792 mg/l, (675±87.2), EC 869-1302 µS cm-1 (1110 ± 143.43), Turbidity 0.02-0.23 NTU (0.15 ±0.06), Na ion 8.7-13.33 mg/l (10.83 ±1.17), K ion 2.7-5 mg/l (4.23 ±0.7), Cl ion 91-.111.7 mg/l (102 ±7.21), Bicarbonate ion 51.7-139.3 mg/l (113.9 ±23.47), Total hardness 289.3-316 mg/l (303.7 ±6.99), Ca ion 213-242 mg/l (227.4 ±8.86), Mg ion 63-84.7 mg/l (76.4 ±6.28), Sulphate ion -23.23-35.4 mg/l (33.52 ±3.68), Phosphate ion 0.02-8 mg/l (5.8 ±2.19), Nitrate ion 39.7-86.1 mg/l (70.73±16.43), Fluoride ion 0-2.13 mg/l (1.07 ±0.50), Fe ion 00-2.13 mg/l (0.013±0.016), Cu ion 0.0 – 0.1 (0.04±0.042), Zn ion 0.0- .72 mg/l (0.223 ±0.28) and heavy metals such as Cd, Cr, and Ni and As were below the detection limit. All the parameters were below the WHO (2012) permissible limit for drinking water.

Keywords: Groundwater; Water quality; Heavy metals; Carcinogenic; Contamination

INTRODUCTION

One of the most vital resources for humans is water. Water is utilised for various purposes, including drinking, irrigation, industrial, domestic, and recreational activities. Approximately 75% of the Earth's surface is covered with water. About 97.5% of this water consists of oceans, which are inaccessible to humans. The remaining 2.5% of freshwater is available to meet human needs and demands. Of this, 24.43 million km^3 are found as ice caps in polar regions, while 10.6 million km^3 serve as freshwater sources such as lakes, reservoirs, and rivers [1]. Due to the growing water demand, surface water resources are becoming inadequate for an increasing population. Therefore, an alternative water source, such as groundwater, is essential, as it is an invaluable yet vulnerable natural resource.

Approximately 43% of the world's groundwater resources are used for irrigation in agriculture [2]. Groundwater is a high-quality freshwater resource and is primarily preferred for agricultural use during dry seasons [3]. In recent times, due to over-exploitation, especially in semi-arid regions, a sharp decline in groundwater level has been observed [4]. In the present decade, groundwater is being contaminated by various factors such as urbanisation, industrial activities, dumping of pollutants, and municipal wastes. Contaminants such as nitrates, heavy metals, pesticides and agricultural runoff can seep into aquifers and affect groundwater quality. If the quality of groundwater is compromised, it can negatively impact all life forms. Therefore, preserving water quality is essential to ensure a sustainable quality of life. Monitoring and assessment of groundwater are crucial for its sustainable management [5]. This study was conducted to assess the physicochemical characteristics of groundwater in Gadarsi village, located in the Kurukshetra district of Haryana.

Study Area

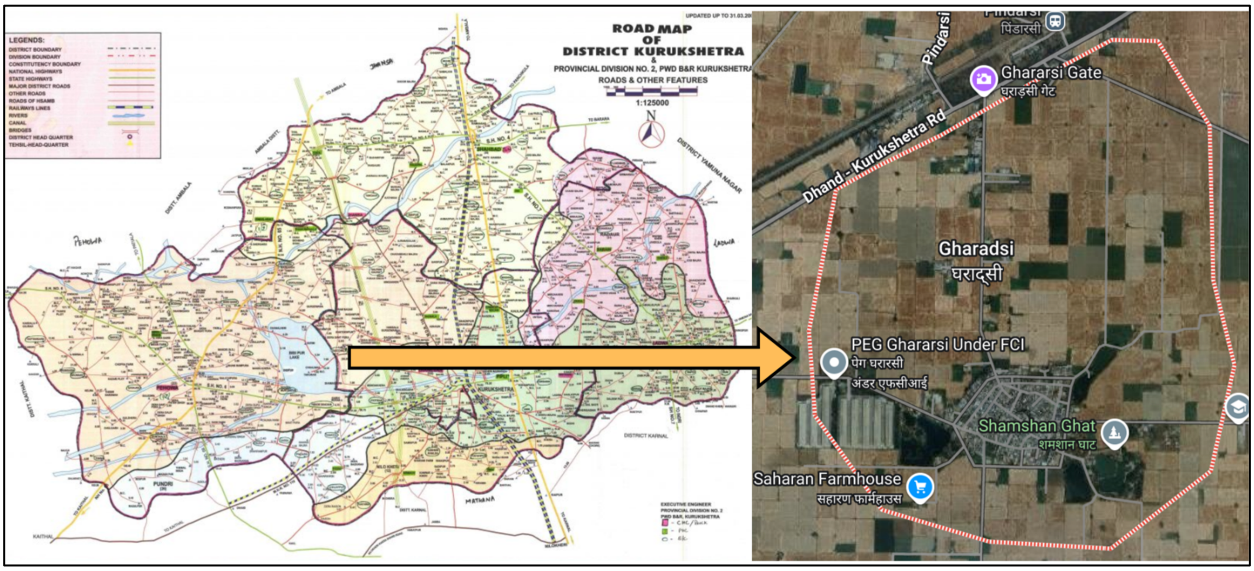

Figure 1. Showing the study area of Gadarsi village Kurukshetra district, Haryana, India

Gadarsi is a village in Thanesar Tehsil situated between 29°0′36.3″n and 76°42″06.6″e within Kurukshetra District of Haryana, India, as shown in Figure 1. It forms part of the Ambala Division and is approximately 18 kilometres west of Kurukshetra, the district headquarters, and 17 kilometres from Thanesar. Gadarsi is close to the border between Kurukshetra District and Karnal District, with Nilokheri Tehsil of Karnal District located to the east. The village has a total population of 2,279 [6]. Despite its small size, it is a significant settlement with a rich cultural heritage and proximity to important towns and administrative centres.

Hydrogeology

In the Kurukshetra district, groundwater is the primary source of drinking water, with its presence detected at various depths. Shallow aquifers exist under both unconfined and semi-confined conditions, while deeper layers are fully confined. The landscape gently slopes from an elevation of 274 to 241 metres above sea level, descending from northeast to southwest. With an average annual rainfall of 582 mm, the moisture distribution is often uneven, contributing to the district's distinctive hydrological character [7].

MATERIALS AND METHODS

Water samples were collected directly from the groundwater sources of households in Gadarsi village during the monsoon season of 2022. Physicochemical analysis was carried out for various water quality parameters such as turbidity, total hardness, bicarbonate ion, calcium, magnesium, chloride, dissolved oxygen, sulphate, phosphate, nitrate, fluoride, and heavy metals including cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), iron (Fe), and lead (Pb), following the standard procedures described in the Standard Methods for the Examination of Water and Wastewater (APHA, 2005) [8].

pH, temperature, total dissolved solids (TDS), and electrical conductivity (EC) were measured using a Hanna Handy digital meter, while turbidity was determined using a digital turbidity meter. Bicarbonate ions, total hardness, calcium, magnesium, chloride ions, and dissolved oxygen were measured using volumetric titration methods. Sulphate, phosphate, nitrate, and fluoride were determined using the spectrophotometric method at different visible wavelengths. Heavy metal ions were analysed using ICP-OES at the Haryana Test House, a NABL-accredited laboratory in Panipat, Haryana.

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RESULTS AND DISCUSSION

Table 1. Statistical Results of Groundwater

Des. Stats	pH	Temp	TDS	EC	TUR	DO	K	Na	Cl	HCO_3	TH	Ca	Mg	SO_4	PO_4	NO_3	F
Mean	8.06	22	675	1110	0.15	4.00	4.2	10.8	103	113.90	304	227	76	34	6	71	1
S. Error	0.13	0	28	45	0.02	0.044	0.2	0.4	2.3	7.42	2	3	2	1	1	5	0
Median	8.20	22	650	1069	0.14	4.2	4.3	10.7	102	120.00	305	227	77	35	6	81	1
Mode	#N/A	22	#N/A	#N/A	#N/A	4	4.3	10.7	91.3	120.00	305	223	77	35	#N/A	#N/A	#N/A
Deviation	0.41	1	87	143	0.06	0.14	0.7	1.2	7.2	23.47	7	9	6	4	2	16	1
S. Variance	0.17	1	7608	20571	0.00	0.37	0.5	1.4	52.0	550.72	49	79	39	14	5	270	0
Kurtosis	1.80	5	-1	-1	0.87	0.04	1.8	2.9	-0.9	6.78	2	0	1	9	7	-1	4
Skewness	-1.66	-1	0	0	-0.69	1.09	-1.2	0.4	-0.3	-2.40	0	0	-1	-3	-2	-1	0
Range	1.27	5	264	433	0.21	0.4	2.3	4.7	20.3	87.67	27	29	22	12	8	46	2
Minimum	7.17	19	529	869	0.02	4	2.7	8.7	91.3	51.67	289	213	63	23	0	40	0
Maximum	8.43	24	792	1302	0.23	4.5	5.0	13.3	112	139.33	316	242	85	35	8	86	2
Sum	80.63	221	6754	11104	1.49	42.4	42.3	108.3	1021	1139.00	3037	2274	764	335	58	707	11
Count	10.00	10	10	10	10.00	10	10.0	10.0	10	10.00	10	10	10	10	10	10	10
Largest (1)	8.43	24	792	1302	0.23	4.5	5.0	13.3	112	139.33	316	242	85	35	8	86	2
Smallest (1)	7.17	19	529	869	0.02	4	2.7	8.7	91	51.67	289	213	63	23	0	40	0
Conf. 95%	0.29	1	62	103	0.04	0.135	0.5	0.8	5.2	16.79	5	6	4	3	2	12	0

Descriptive statistical analysis in Table 1 revealed that the data for all parameters were normally distributed. Most parameters fell within the WHO (2012) drinking water specifications, except for TDS and nitrate, which could be attributed to agricultural runoff and the influence of parent bedrocks in the groundwater. The findings indicate that key parameters, including pH (7.2–8.4), temperature (19.47–24.07°C), TDS (528–792 mg/L), and EC (869–1302 μS/cm), generally meet the WHO (2012) standards for drinking water [9].
Notably, heavy metals were found to be below detection limits, ensuring safety. However, TDS levels exceeded the recommended limits, indicating high concentrations of dissolved salts and minerals. Elevated TDS can affect the taste of water and may be harmful to health in the long term. WHO guidelines recommend a TDS level of 500 mg/L for good-quality drinking water, while levels above 1000 mg/L are considered undesirable. The TDS levels observed in this study exceeded the recommended limits, suggesting that the groundwater in the area may not be fully suitable for drinking purposes. Nitrate levels in groundwater often exceed the WHO (2012) limit of 45 mg/L due to agricultural runoff, including excess fertilisers and animal waste in the surrounding area. This contamination is a serious global concern, particularly in intensive farming regions. High nitrate concentrations primarily result from diffuse sources such as surface runoff and livestock operations, posing health risks such as methemoglobinemia [10].

CORRELATION SUMMARY

Results showed that the range of most parameters was within the permissible limit for drinking water. Statistical analysis, as shown in Tables 2 and 3, revealed a strong positive correlation between bicarbonate (HCO_3^-) ions and sulfate and phosphate ions, indicating that alkalinity increases with higher concentrations of these ions. This relationship is influenced by water composition and human activities that share phosphate and sulfide mineral sources. HCO_3^- ions help stabilise aquifer pH, with their accumulation occurring on pump surfaces, especially in industrial areas. Groundwater pH is closely linked to temperature, bicarbonate, and phosphate concentrations. Higher pH levels often accompany increases in HCO_3^- and phosphate, while rising temperatures can reduce pH by impacting ion solubility.
Turbidity, caused by suspended particles like silt, results from both natural erosion and human activities [11]. Sodium ions further contribute to this turbidity through weathering and runoff. Phosphate and potassium predominantly stem from fertiliser use and untreated wastewater, and elevated concentrations can pose significant risks to groundwater quality [12]. Groundwater depth also affects bicarbonate levels; shallow waters release carbon dioxide from organic matter, raising bicarbonate levels, while deeper groundwater maintains more stable levels due to mineral dissolution.
A moderate positive correlation exists between turbidity and pH, where increased turbidity elevates alkalinity. Dissolved oxygen (DO) influences pH through the decomposition of organic matter, linked to agricultural nitrification. High temperatures raise total dissolved solids (TDS) and electrical conductivity (EC), indicating increased ionic content. Sodium strongly correlates with calcium and magnesium, with DO levels higher in shallow waters and declining with salinity. Potassium correlates with total hardness, calcium, and magnesium, but inversely affects magnesium concentrations. Chloride positively correlates with sulfate but negatively with magnesium and fluoride. Bicarbonate consistently correlates with calcium and nitrate due to $CaCO_3$ dissolution, while DO generally shows a negative correlation with bicarbonate. Total hardness correlates positively with nitrate and DO, mainly due to agricultural practices. Phosphate and DO rise together, primarily due to decreased biological activity in groundwater. Many weak correlations were identified, but they may be negligible.

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Table 2. Correlation analysis

	pH	**Temp**	**TDS**	**EC**	**TURB**	**Na**	**K**	**Cl**	**HCO_3**	**TH**	**Ca**	**Mg**	**SO_4**	**PO_4**	**NO_3**	**F^-**	**DO**	**Depth**
pH	1																	
Temp	0.81	1.00																
TDS	0.56	0.74	1.00															
EC	0.56	0.74	1.00	1.00														
TURB	0.35	0.64	0.35	0.35	1.00													
Na	0.56	0.62	0.57	0.57	0.75	1.00												
K	0.60	0.63	0.37	0.37	0.50	0.22	1.00											
Cl	0.19	0.11	-0.14	-0.14	0.21	0.22	-0.14	1.00										
HCO_3	0.90	0.80	0.54	0.54	0.53	0.61	0.68	0.21	1.00									
TH	0.61	0.61	0.29	0.29	0.67	0.79	0.29	0.55	0.69	1.00								
Ca	0.49	0.48	-0.06	-0.06	0.64	0.41	0.48	0.63	0.49	0.71	1.00							
Mg	-0.01	0.01	0.41	0.41	-0.17	0.30	-0.36	-0.28	0.08	0.11	-0.62	1.00						
SO_4	0.74	0.85	0.59	0.59	0.72	0.61	0.74	0.31	0.91	0.72	0.60	-0.05	1.00					
PO_4	0.79	0.69	0.36	0.36	0.57	0.52	0.76	0.16	0.96	0.67	0.53	-0.01	0.89	1.00				
NO_3	0.27	0.39	0.47	0.47	0.70	0.63	0.60	-0.06	0.47	0.39	0.25	0.08	0.61	0.54	1.00			
F^-	0.17	0.39	0.39	0.38	-0.21	-0.05	-0.10	-0.32	0.03	-0.01	-0.31	0.43	-0.02	-0.10	-0.4	1		
DO	0.33	0.05	-0.6	-0.17	0.16	0.25	-0.2	0.56	0.32	0.29	0.4	-0.25	0.15	0.25	-0.16	-0.42	1	
Depth	-0.71	-0.80	-0.61	-.61	-0.8	0.11	0.13	-0.3	-0.84	-0.88	-0.60	-0.13	-0.90	0.02	-0.7	0.02	-0.05	1

Table 3. Correlation Results of Physico-chemical parameters of Groundwater

	pH	temp	TDS	EC	TURB	Fe	Cu	Zn	Pb
pH	1								
temp	0.81	1.00							
TDS	0.56	0.74	1.00						
EC	0.56	0.74	1.00	1.00					
TURB	0.35	0.64	0.35	0.35	1.00				
Fe	0.10	-0.06	0.25	0.25	-0.23	1.00			
Cu	-0.03	0.36	0.29	0.29	0.41	-0.24	1.00		
Zn	-0.16	0.03	-0.10	-0.10	0.30	-0.38	0.47	1.00	
Pb	0.08	0.23	0.08	0.08	-0.21	-0.32	0.16	0.45	1.00

CONCLUSION

A comprehensive groundwater quality assessment conducted in Gadarsi village, Kurukshetra, Haryana, analysed 10 samples during the post-monsoon season of 2022. Gadarsi, home to 2,279 residents (Census 2011), demonstrates a clear link between agricultural practices and water quality, particularly affecting TDS and nitrates due to runoff. Strong positive correlations between bicarbonate, sulfate, and phosphate ions underscore the significant human impact on groundwater quality. This assessment highlights the critical need for continued monitoring and management to safeguard this vital resource.

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Ethical Approval
The samples were collected according to APHA (2005) guidelines. Verbal consent was obtained from the respective owners for the groundwater samples, and the purpose of the study was clearly explained to them.

Consent to Participate
All co-authors have agreed.

Consent to Publish
All co-authors have agreed

Data Availability Statements
Data will be available on demand.

Authors Contributions
Hardeep Jhanjohtra conducted the fieldwork, laboratory analysis, and prepared the original draft of the manuscript. Sakshi Narula and Sandeep Royal contributed to the data analysis and manuscript writing. Geetanjli Sahni assisted in editing the manuscript, compiling the data, and making final corrections. Hardeep Rai Sharma developed the concept, supervised the research, and edited the manuscript. All authors reviewed and approved the final version of the manuscript.

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Competing Interests
All authors affirm that they have no competing financial or personal conflicts of interest that could potentially have an impact.

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