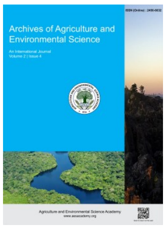
Archives of Agriculture and Environmental Science 11(2): 181-189 (2026)
https://doi.org/10.26832/24566632.2026.110205

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



ORIGINAL RESEARCH ARTICLE

Evaluation of ground water quality of Saharanpur constituency in Uttar Pradesh, India

Sachin Srivastava* and **Gaurav Aggarwal**

Department of Agricultural Studies, Quantum University, Mandawar (N.H. 73), Roorkee-Dehradun Highway, Roorkee - 247662 (Uttarakhand), India
*Corresponding author's E-mail: sachin.env@gmail.com

ARTICLE HISTORY

Received: 10 March 2026
Revised received: 20 May 2026
Accepted: 28 May 2026

Keywords

Correlation
Industrialisation
Regression
Urbanisation
Water quality

ABSTRACT

This study was conducted to evaluate the groundwater quality at designated sites in the Saharanpur area of Uttar Pradesh, India, focusing on key physicochemical attributes and their statistical relationships. Water samples were collected from four sites and analysed using standard assessment methods. The parameters measured included temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total alkalinity (TA), total hardness (TH), and major ions. The results showed that groundwater quality was largely within acceptable limits for municipal and agricultural use. Temperature ranged from 24.67±1.53 to 29.33±1.22°C, and pH values varied between 6.71±0.51 to 7.26±0.27, indicating a slightly acidic to neutral nature EC and TDS levels ranged from 0.57±0.03 to 0.97±0.08 dS m^{-1} and 198.31±10.09 to 263.65±11.13 mg L^{-1}, respectively, reflecting low salinity. DO values ranged from 5.24±0.56 to 6.55±0.15 mg L^{-1}, while BOD (1.52±0.27–1.98±0.08 mg L^{-1}) and COD (4.88±1.57–8.69±1.43 mg L^{-1}) indicated limited organic load. TA and TH suggested the water was relatively mineral-rich. Statistical analysis revealed significant positive relationships among EC, TDS, and major ions, whereas DO and pH showed opposite trends with salinity parameters. The study highlights that although groundwater quality is currently safe, increasing human-induced stress may progressively alter regional hydrochemistry, necessitating continuous monitoring and well-planned groundwater management strategies for long-term sustainability.

Citation of this article: Sachin, S., & Aggarwal, G. (2026). Evaluation of ground water quality of Saharanpur constituency in Uttar Pradesh, India. *Archives of Agriculture and Environmental Science*, *11*(2), 181-189, https://dx.doi.org/10.26832/24566632.2026.110205

INTRODUCTION

Accelerated urban expansion and industrial development are the primary causes of groundwater contamination, as expanding metropolitan cities and industrial parks generate immense quantities of wastewater and sewage that frequently percolate into aquifers (Kumar *et al.*, 2024; Martins & Mafimisebi, 2024). Urban expansion transforms natural landscapes into impervious surfaces, thereby reducing natural recharge and increasing the accumulation of contaminants in shallow aquifers through leaching processes. The seepage and penetration of untreated wastewater into subsurface formations can cause severe groundwater contamination (Jasechko *et al.*, 2024). Furthermore, the increased generation of wastewater raises the concentration of hazardous chemicals that infiltrate the subsurface environment, resulting in the continuous degradation of groundwater quality (Karunanidhi *et al.*, 2021; Chaudhary *et al.*, 2025). These conditions are particularly severe in developing regions where wastewater treatment infrastructure cannot keep pace with growing urban and industrial development, thereby threatening the long-term sustainability of one of the most accessible freshwater resources. Reports indicate that up to 60% of groundwater in some industrialised regions has been found to be contaminated (Chaudhary *et al.*, 2025).

Groundwater constitutes the principal source of freshwater for the global population and is extensively utilised for domestic, agricultural, and industrial purposes. Approximately one-third of the world's population depends on groundwater as the primary source of drinking water (Karunanidhi *et al.*, 2021). Although freshwater represents only a small fraction of the Earth's total water resources, a substantial portion of the usable supply is stored beneath the surface in aquifers, making groundwater the largest accessible freshwater reserve. Nearly half of the global population relies on groundwater for drinking purposes, while a significant proportion of irrigated agriculture depends on it, emphasising its crucial role in food security and livelihood sustainability (FAO, 2024; UNESCO, 2024). Groundwater is also comparatively more resilient to short-term climatic variability than surface water, thereby acting as an important buffer during droughts and seasonal water shortages. However, increasing water demand, rapid urbanisation, industrial growth, and unsustainable extraction practices are placing immense anthropogenic stress on groundwater resources, resulting in declining per capita availability and deterioration of water quality (UCL, 2024; FAO, 2024).

The present global scenario reveals a rapid decline in groundwater quality due to contamination arising from diverse anthropogenic activities such as industrial operations, agricultural practices, military activities, and research-related discharges. These contamination problems are often aggravated by insufficient awareness, inadequate planning, negligence, and the high cost associated with proper waste treatment and disposal methods (Kumar *et al.*, 2018; Bano *et al.*, 2026). Consequently, untreated or partially treated wastes are frequently discharged into the environment, causing severe pollution of groundwater resources. Increasing industrialisation and expanding urbanisation have given rise to groundwater contamination, which occurs when pollutants are discharged to the ground and make their way down to the groundwater. Pollution can take place from on-site sanitation systems, landfills, effluent from wastewater treatment plants, leaking sewers, petrol filling stations or from over-application of fertilisers in agriculture (Sarker *et al.*, 2021; Kumar *et al.*, 2024). Therefore, restoration and protection of groundwater reserves through effective monitoring, management, and preventive strategies are essential for ecosystem sustainability and human welfare (Badar *et al.*, 2024).

Saharanpur, situated in the northernmost part of the Ganga–Yamuna Doab at the foothills of the Shivalik range, occupies a strategically important geographical position between the Himalayan foothills and the Upper Gangetic Plains. The district lies between Latitude 29°34'45'' N to 30°21'30'' N and Longitude 77°09′00″ E to 78°14'45'' E, with an average elevation of 290 m above sea level. Saharanpur is historically significant and well known for its intricate wood-carving handicraft industry, agricultural markets, and the presence of the Institute of Paper Technology (DSA, 2026). The district experiences a sub-humid tropical climate influenced by the Himalayan foothills and supports diverse commercial, industrial, and agricultural activities. Owing to rapid urbanisation, industrial expansion, and excessive dependence on aquifers for domestic and agricultural requirements, groundwater resources in Saharanpur are presently under considerable environmental stress (Sridhar & Parimalarenganayaki, 2025). Previous studies have reported groundwater in several regions to exhibit neutral to alkaline pH (7.2–9.7); however, elevated Total Dissolved Solids (248.7–870 mg/L) and heavy metal contamination frequently render the water unsuitable for safe consumption and utilisation (Choden *et al.*, 2020).

Despite the increasing environmental concern regarding groundwater contamination in rapidly developing urban centres, limited studies are available focusing on the comprehensive physico-chemical assessment of groundwater quality in Saharanpur district under the combined influence of urbanisation and industrialisation. Most earlier investigations have concentrated only on selected parameters or localised regions, leaving a significant research gap in understanding the integrated impact of anthropogenic activities on groundwater quality characteristics in this region (Kumar *et al.*, 2019; Khare *et al.*, 2020). Therefore, continuous monitoring and scientific evaluation of groundwater quality are necessary to formulate effective management strategies and regulatory policies for minimising environmental risks associated with wastewater contamination, improving groundwater sustainability, protecting aquatic ecosystems, and safeguarding public health.

Keeping in view the growing concern regarding groundwater contamination, the present study was undertaken to evaluate the impact of urbanisation and industrial development on groundwater quality in different regions of Saharanpur (Uttar Pradesh), India. The study aims to analyse important physico-chemical parameters, including temperature, electrical conductivity (EC), pH, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), alkalinity, hardness, chloride (Cl^-), sodium (Na^-), and potassium (K^-) in groundwater samples. The novelty of the present investigation lies in providing a comprehensive assessment of groundwater quality in relation to increasing anthropogenic activities in Saharanpur, thereby generating scientific information useful for environmental monitoring, sustainable groundwater management, and future policy formulation.

MATERIALS AND METHODS

Sampling locations

The present study was conducted at various sampling sites to measure the following physicochemical parameters. The following sites were selected for the present study at Saharanpur (29° 58' 12" N and 77° 33' 36" E) (Uttar Pradesh). The Transport Nagar (Site-I), Gagalheri (Site-II), Himmat Nagar (Site-III) and Pilkhani (Site-IV) sampling sites were selected for the present study (Figure 1).

Sample collection and analytical assessment

Groundwater samples were collected over six months from January 2025 to June 2025 to evaluate various physicochemical parameters. A total of four sampling locations were selected, comprising one tube well, one hand pump, and two borehole

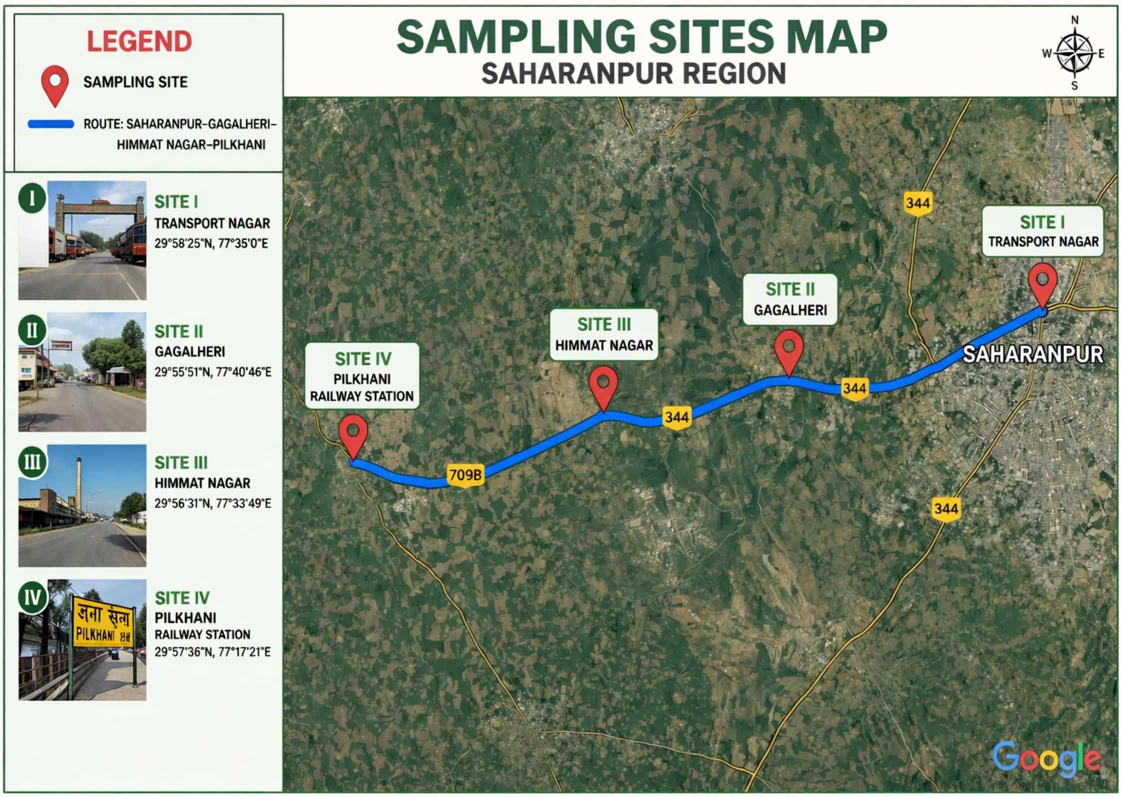


Figure 1. *Map showing different sampling sites at Saharanpur constituency (Sources: Google map).*

taps within the study area. Sampling was conducted at fortnightly intervals, with collections carried out twice a month during morning hours between 7:00 AM and 10:00 AM. All water samples were obtained using properly cleaned and sterilised bottles to avoid contamination. After collection, the samples were immediately preserved on ice and transported to the laboratory, where they were stored in a deep freezer at approximately −20° C until further analysis. For each sampling site, samples were collected in triplicate, and the mean values of the measured parameters were reported to ensure accuracy and reliability. Physico-chemical analysis of the samples was completed within 48 hours of collection. During this period, samples were maintained at room temperature as required for specific tests. A standard field sampling kit was used during collection, which included sample bottles, reagents, glassware, a pH meter, a thermometer, and other necessary instruments for on-site observations. Samples for different physico-chemical parameters were collected simultaneously to maintain consistency in analysis.

Water analysis method

The collected water samples were examined for a range of important physicochemical characteristics. These included temperature (°C), electrical conductivity (EC, $dS\ m^{-1}$), and total dissolved solids (TDS, mg/L). In addition, parameters such as pH (indicating hydrogen ion concentration), dissolved oxygen (DO, mg/L), biochemical oxygen demand (BOD, mg/L), and chemical oxygen demand (COD, mg/L) were measured. Further analysis was carried out to determine chloride concentration (Cl^-, mg/L), alkalinity (mg/L), and total hardness (TH, mg/L). The concentrations of essential cations, namely sodium (Na^+, mg/L) and potassium (K^+, mg/L), were also estimated to assess overall water quality using standard methods (APHA, 2023; Trivedy & Goel, 1986). Samples were analysed for the physico-chemical parameters.

Data interpretation

The data obtained from the study were subjected to statistical evaluation to interpret variations among different sampling sites. Correlation analysis was performed using Karl Pearson's coefficient of correlation to examine the relationships between various physico-chemical parameters of groundwater across Site I, Site II, Site III, and Site IV. In addition, descriptive statistics such as mean and standard deviation (SD) were calculated to assess the variability and distribution of the data. These statistical computations were carried out using MS Excel (2024), ensuring accurate and systematic data analysis.

RESULTS AND DISCUSSION

Alterations in physico-chemical properties of GW in Saharanpur at Site-I (Transport Nagar), Site-II (Gagalheri), Site-III (Himmat Nagar) and Site-IV (Pilkhani) sampling sites are appended in Table 1. The physico-chemical analysis of GW showed that the quality of GW at all four sites (Site-I to Site-IV) was still under the permissible limit as prescribed by ISI and WHO. But due to increasing urbanisation and industrialisation at these sites of Saharanpur, the GW quality will further deteriorate.

Temperature

Temperature is one of the most noteworthy features that impact nearly all the physical, chemical and biological characteristics of water and thus the water chemistry. Rising groundwater temperatures, driven by climate change and urban heat, decrease dissolved oxygen and degrade water quality by enhancing microbial activity and mineral weathering. Warmer groundwater can increase hazardous contaminant concentrations (e.g., arsenic, manganese) and significantly accelerate aquifer depletion rates (Bhattarai *et al.*, 2023). Temperature regulates key biological and chemical processes that affect the cycling of oxygen, carbon and other elements in soil and groundwater.

During the present study, the temperature of GW samples was found in an agreeable range in all the sampling months (January-June) and at all the sampling sites (I-IV) (Table 1). The maximum temperature (29.33°C) was recorded at Site IV, while the minimum Temperature (24.67°C) was recorded at Site I. The observed condition at Site IV may be attributed to intensifying pollution levels triggered by the emancipation of industrial effluents, along with raised air temperatures. These aspects likely contribute to thermal alterations in the natural water system. This was in accordance with Matta *et al.* (2020), they recorded maximum temperature (23.66°C) at Ibrahumpur and minimum (22.33°C) in Sarai area of Haridwar district, Uttarakhand.

EC

EC in groundwater measures its capability to conduct electrical current, directly reflecting the concentration of dissolved ions, salts, and minerals. High EC indicates higher salinity and impurity levels, impacting water potability and irrigation suitability. Key impacts include signalling seawater intrusion in coastal aquifers, identifying pollution events, and affecting soil salinity and plant health. During the present study, EC of GW samples were found in a satisfying range in all the sampling months (January-June) and at all the sampling sites (I-IV) (Table 1). The maximum EC (0.97 dSm^{-1}) was recorded at site III, while the minimum EC (0.57 dSm^{-1}) was recorded at site I. Elevated EC values at Site III indicate the accumulation of pollutants, leading to an increase in groundwater salinity. The variation in EC across the study area reflects differences in groundwater quality, which, based on field observations, can be linked to nearby industrial activities and waste disposal sites. The rise in EC suggests a higher concentration of dissolved ions in the water, a trend that is further supported by corresponding increases in salinity levels. Bano *et al.* (2026) also reported elevated levels of EC from (968 to 2483 μS/cm) at different sites of Firozabad, Uttar Pradesh, while its ideal value is <2400 μs/cm, with a distinct hotspot of very high conductivity (red-yellow zone) in the central region. This high EC indicates elevated dissolved salt concentrations, likely from anthropogenic sources such as industrial discharge, sewage contamination, or agricultural runoff, signalling poor water quality and potential unsuitability for drinking in affected areas.

TDS

TDS in water arise from both natural sources and anthropogenic activities such as mining and industrial processes. These dissolved constituents mainly comprise various inorganic salts, such as chlorides, phosphates, carbonates, bicarbonates, and nitrates - along with elements like calcium, sodium, potassium, magnesium, and manganese, as well as organic substances and fine particulates. Higher TDS concentrations reflect an increased presence of dissolved materials in groundwater, which can enhance the mobility and dispersion of other contaminants, including heavy metals and organic pollutants. Additionally, excessive TDS levels deteriorate water quality, rendering it unsuitable for drinking and restricting its use for domestic purposes.

During the present study, TDS of GW samples were found under the permissible range in all the sampling months (January-June) and at all the sampling sites (I-IV) (Table 1). The maximum TDS (263.65 mg/l) was recorded at Site III, while the minimum TDS (198.31 mg/l) was recorded at Site I. This can be attributed to the continuous discharge of untreated or partially treated wastewater, which adds more dissolved constituents, especially when the capacity for natural dilution remains low. These findings are consistent with a recent study at different locations of Kanpur city, Uttar Pradesh, where elevated TDS ranges were recorded to be 510.90 to 536.90 mg/l (Nayak, 2025). The presence of elevated dissolved solids can be linked to the release of industrial effluents and municipal waste in the region. During both seasons—particularly under low rainfall conditions-the recharge of fresh water into the aquifer is reduced. This decreased inflow limits the natural dilution process within groundwater, allowing dissolved substances to accumulate. Additionally, during dry conditions, capillary movement draws water upward from deeper soil layers, conveying dissolved salts with it. These salts may later re-dissolve and infiltrate back into the groundwater system, eventually contributing to an upsurge in total dissolved solids (TDS) concentrations.

pH

pH is a key indicator used to describe the acidic or basic nature of water, based on the concentration of hydrogen ions present. The pH level significantly influences chemical interactions, biological activity, and the behaviour of dissolved substances in water. Natural factors such as geological formations and dissolved gases, along with human activities like industrial effluents and agricultural practices, can alter pH levels. During the present study pH of GW samples were found under the permissible range as prescribed by WHO and BIS in all the sampling months (January-June) and at all the sampling sites (I-IV) (Table 1). In the present study, the pH values were in the range (6.71-7.26). The least value was recorded to be 6.71 at site-IV, while maximum was recorded to be 7.26 at Site-I. This was in consideration with Kumar *et al.* (2019) reported pH in the study ranged from 6.5 - 7.5 and it was within the permissible limit (BIS, 2012) and below the drinking water guidelines (WHO, 2011) in the ground water samples of River Hindon catchment of Saharanpur, Uttar Pradesh, India. Meghanad *et al.* (2024) reported the pH range (6.96-7.65 mg/L) eastern and western parts the riverside of Tiruchirappalli District in the central parts of Tamil Nadu, India, which has diverse fields of agricultural productivity and industrial activities.

DO, BOD and COD

DO plays a vital part in defining groundwater quality by manipulating both metal solubility and microbial processes. When DO levels fall in low category, it often signals contamination and forms environments that enhance the release of certain metals such as iron, manganese and arsenic into the water. Low level oxygen environments are characteristically allied with the existence of organic matter, which consumes oxygen during decomposition. In contrast, higher DO concentrations are characteristic of clean and well-oxygenated water. Throughout the current study DO of GW samples were found under the permissible range in all the sampling months (January-June) and at all the sampling sites (I-IV) (Table 1). The DO levels were recorded moderately higher at Sampling Site I (6.55 mg/L) compared to Site II (6.40 mg/L), these observations suggest amended oxygen availability at these sites, whereas reduced DO levels were noted at Site III (5.24 mg/L) and Site IV (5.55 mg/L). DO concentrations in groundwater samples from Sites I–IV were consistently above 5 mg/L, indicating generally toxic conditions within the aquifer system. However, relatively reduced DO levels at Sites III and IV may be associated with the infiltration of effluents originating from nearby distillery and sugar mill operations. These effluents are typically categorized by high organic load and elevated concentrations of biodegradable matter, which stimulate microbial respiration and upsurge biochemical oxygen demand (BOD). The subsequent consumption of dissolved oxygen during microbial degradation processes, along with limited natural re-aeration in subsurface environments, likely contributes to the observed decline in DO levels in these locations.

Throughout the current investigation, the Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) concentrations of groundwater samples persisted within acceptable limits across all sampling sites (I–IV) and throughout the study period (January-June). The elevated levels of BOD and COD values (1.98 mg/L and 8.69 mg/L, respectively) were observed at Site III, whereas the lowest values (1.52 mg/L and 4.88 mg/L) were recorded at Site II. The moderately elevated levels at Site III may be attributed to the ingress of organic-rich contaminants, likely originating from surface runoff, improper solid waste disposal, and anthropogenic activities. Such inputs can introduce biodegradable and oxidizable substances into the subsurface environment, thereby increasing oxygen demand in groundwater systems.

In accordance with the above concentrations of DO, BOD and COD, Matta *et al.* (2016) also recorded DO between the ranges of 5.00 to 8.20 mg/l, BOD was recorded between the ranges of 2.80 to 4.90 mg/l, COD between the ranges of 5.00 to 10.00 mg/l of ground water samples at different sites of at Dhampur, District-Bijnor (U.P.) India. This might be due to intensified urbanization and industrialization contribute significantly to elevated BOD and COD levels through the discharge of organic-rich effluents and chemically oxidizable substances into the environment. These inputs enhance microbial activity and oxidation processes, thereby increasing the consumption of dissolved oxygen. As a result, the elevated oxygen demand leads to a decline in DO levels, ultimately disturbing the natural redox balance of the groundwater system. Similarly, Meghanad *et al.* (2024) noted that BOD values varied from 48.01 to 149.97 mg/L, averaging 79.72 mg/L. The value of COD ranges from 23.04 to 94.97 mg/L, with a mean value of 47.32 mg/L. The high levels of BOD and COD are recorded in 56 groundwater samples were collected from bore wells and dug wells in the Cauvery River Basin within the Tiruchirappalli District, which reveal increasing contamination with mostly biodegradable matters due to domestic sewage and untreated industrial effluents.

Total alkalinity (TA) and total hardness (TH)

Total hardness is a key physico-chemical property of water, mainly caused by dissolved calcium and magnesium salts such as carbonates, bicarbonates, sulphates, and chlorides. The permissible limit for drinking water is 300 mg/L, and higher levels may be associated with potential health risks, including kidney and heart problems (Crowther *et al.*, 2025). Alkalinity refers to the acid-neutralizing capacity of water and is primarily due to the presence of carbonates, bicarbonates, and hydroxides, along with other minor bases. It indicates the buffering capacity of water and reflects the presence of natural dissolved salts. Variations in hardness and alkalinity among the sampled water sources underscores the influence of geological, hydrological, and anthropogenic factors. Natural processes such as weathering of minerals and dissolution of carbonate rocks contribute to the enrichment of calcium, magnesium, carbonate, and bicarbonate ions in water. Anthropogenic activities such as industrial discharge, agricultural runoff, and urbanization can exacerbate hardness and alkalinity levels, posing risks to water quality and ecosystem integrity (Maske *et al.*, 2025).

Through the current study alkalinity and TH of GW samples were found under the permissible range in all the sampling months (January-June) and at all the sampling sites (I-IV) (Table 1). The maximum alkalinity/TH (263.56/296.43 mg/l) was recorded at site IV, while minimum alkalinity/TH (231.41/256.87 mg/l) was recorded at Site-I.

Water hardness mainly originates from sewage discharge and surface runoff, particularly from calcareous soils and limestone-rich areas. It may also result from leaching of construction materials containing calcium compounds, as well as from industrial effluents enriched with magnesium salts, which collectively increase the concentration of hardness-causing ions in water as reported earlier (Sachin, 2020 and Belal *et al.*, 2024). This was in accordance with Choden *et al.* (2020) who reported hardness high 160 to 450 mg/l Kamdhanu Industrial area and 113 to 406 mg/l in Industrial area Delhi Road, Saharanpur. They observed $CaCO_3$ hardness is found to be higher than BIS limit (300 mg/l) in 4 locations of Saharanpur. The probable cause for excessive hardness appears to be the source rocks in the Himalayan foothills towards the north from where groundwater is recharged. The alkalinity varies in the range of 168-564 mg/l and 230-568 mg/l in Kamdhanu Industrial area and Industrial area Delhi

Road, Saharanpur respectively. However, high concentration of alkalinity in drinking water is not known to cause any direct noticeable effects on human health. Also, Manna *et al.* (2024) who reported hardness (330 PPM) and alkalinity (310 PPM), which were above the WHO recommendations for drinking water guidelines in different areas of Alwar district of Rajasthan, India. Correspondingly (Nayak, 2025) also reported an increasing trend in ground water samples for total hardness (259.30-290.87 mg/l) and alkalinity (190.76-276.45 mg/l) in the different sampling locations of Kanpur, Uttar Pradesh, India.

Cl^-

All type of natural and raw water contains chlorides. Groundwater contamination by chloride arises from road salt runoff, seawater intrusion, sewage, and industrial waste, significantly degrading water quality. Levels exceeding 250 mg/L impart a salty taste, corrode infrastructure, and damage aquatic ecosystems. While not acutely toxic to humans at low levels, high concentrations indicate severe pollution (Mackie *et al*., 2022). During the present study Cl^- of GW samples were found under the permissible ranges in all the sampling months (January-June) and at all the sampling sites (I-IV) (Table 1). The maximum Cl^- (20.77 mg/l) was recorded at site IV, while minimum Cl^- (10.21 mg/l) was recorded at Site-I. This was in consideration with Choden *et al.* (2020) they recorded Cl^- (7.1-135 mg/l) in Kamdhenu Industrial area and (25.5-113.44 mg/l) in Industrial area Delhi Road, Saharanpur. It is found that all the values are within the limits permitted by BIS Standards. Ali *et al.* (2024) also reported concentration of chloride ranged from 226 to 814 ppm with the average value of 470 ppm. Similarly, Kumari *et al.* (2025) reported Cl^- concentration in water samples ranging from 14.2 to 128 mg/L (mean value: 55 mg/L) in ground water samples of different regions of Prayagraj District, Uttar Pradesh under permissible limit High concentration of Cl^- in water inhibits the microbial activity and consumption may cause laxative effect.

Na^+ and K^+

High concentrations of sodium ions in drinking water can contribute to cardiovascular issues. When sodium levels in groundwater become excessive, they often reduce the taste quality and overall acceptability of the water. Potassium present in groundwater primarily originates from the natural breakdown and weathering of igneous and metamorphic rocks. The impact of sodium (Na^+) and potassium (K^+) on groundwater contamination is characterized by increasing salinity, significant degradation of soil structure for agriculture, and rising health risks in rapidly urbanizing and industrialized areas. While these elements are natural, their elevated presence is largely driven by anthropogenic factors, specifically fertilizer runoff, untreated industrial waste, and sewage (Sonawane *et al*., 2024). Throughout the present study Na^+ and K^+ of GW samples were found under the permissible range in all the sampling months (January-June) and at all the sampling sites (I-IV) (Table 1). This was in accordance with Khare *et al.* (2020) they recorded maximum Na^+/K^+ (130/1.50 mg/l) at Nakur/Sadauli kadim areas of Saharanpur District, Uttar Pradesh, India. Bhushan *et al.* (2025) also recorded maximum/minimum range of Na^+/K^+ (140-7.60/20.0-3.1 mg/l) in GW samples of Sultanpur, District, Uttar Pradesh, India.

Correlation and regression analysis

The correlation coefficients (r) value among each parameter and different sites were presented in Table 2. Throughout the present study the correlation analysis of physicochemical parameters across the four sampling sites reveals key hydrochemical relationships controlling water quality. A very strong positive correlation between EC and TDS (r = +0.99) confirms that dissolved ions govern conductivity. Similarly, strong associations among Na⍰, Cl⍰, and K⍰ indicate a common origin, likely from mineral weathering or anthropogenic inputs such as agricultural runoff. Total hardness and alkalinity are also strongly correlated, suggesting the influence of carbonate and bicarbonate ions. In contrast, pH and dissolved oxygen (DO) show negative correlations with major ions and TDS, indicating that increased salinity may reduce pH and oxygen availability. BOD and COD exhibit a strong positive relationship (r = +0.93), reflecting the presence of organic pollution linked with higher ionic load. Temperature shows moderate positive correlations with EC, TDS, and COD, suggesting its role in enhancing chemical reactions and microbial activity. Overall, the results indicate that ionic composition, organic pollution, and oxygen dynamics are closely interconnected, though interpretations should be made cautiously due to limited data.

Table 1. Groundwater quality parameters at different sites of Saharanpur, Uttar Pradesh (India).

Parameter	Sites				Permissible limit	
	Site I	Site II	Site III	Site IV	BIS (2012)	WHO (2011)
Temperature (°C)	24.67±1.53	27.00±2.00	29.33±1.22	25.56±1.53	28-30	-
EC dS m^{-1}	0.57±0.03	0.89±0.10	0.97±0.08	0.88±0.13	2000	-
TDS (mgL^{-1})	198.31±10.09	242.68±4.04	263.65±11.13	243.34±21.85	500-2000	500
pH	7.26±0.27	7.24±0.10	6.76±0.19	6.71±0.51	6.5-8.5	6.5–8.5
DO (mgL^{-1})	6.55±0.15	6.40±0.64	5.24±0.56	5.55±0.72	8	-
BOD (mgL^{-1})	1.55±0.46	1.52±0.27	1.98±0.08	1.91±0.16	28-32	-
COD (mgL^{-1})	4.97±0.96	4.88±1.57	8.69±1.43	7.22±1.49	500	-
TA (mgL^{-1})	231.41±11.82	240.52±11.27	244.85±10.38	263.56±7.56	200-600	-
TH (mgL^{-1})	256.87±12.70	266.66±13.00	277.62±12.27	296.43±12.70	200-600	500 as $CaCO_3$
Cl^- (mgL^{-1})	10.21±0.40	15.44±2.94	18.62±2.96	20.77±3.43	250-1000	250
Na^+ (mgL^{-1})	10.22±0.84	12.36±1.40	15.76±1.25	16.22±1.61	200	200
K^+ (mgL^{-1})	4.23±0.39	4.88±0.46	6.32±1.67	7.22±0.56	12	-

The values are mean ± SD of six replicates.

Table 2. Correlation matrix among the various physico-chemical parameters at different sites (I-IV).

Parameter	Temperature	EC	TDS	pH	DO	BOD	COD	TA	TH	Cl^-	Na^+	K^+
Temperature	1.00	0.8	0.85	-0.42	-0.64	0.52	0.67	0.06	0.16	0.47	0.53	0.32
EC	0.8	1.00	0.99	-0.64	-0.74	0.62	0.66	0.58	0.63	0.86	0.82	0.69
TDS	0.85	0.99	1.00	-0.69	-0.8	0.69	0.74	0.55	0.61	0.85	0.84	0.7
pH	-0.42	-0.64	-0.69	1.00	0.89	-0.78	-0.71	-0.79	-0.86	-0.89	-0.96	-0.96
DO	-0.64	-0.74	-0.8	0.89	1.00	-0.86	-0.83	-0.75	-0.82	-0.85	-0.94	-0.88
BOD	0.52	0.62	0.69	-0.78	-0.86	1.00	0.93	0.72	0.79	0.81	0.92	0.89
COD	0.67	0.66	0.74	-0.71	-0.83	0.93	1.00	0.74	0.8	0.75	0.87	0.8
Alkalinity	0.06	0.58	0.55	-0.79	-0.75	0.72	0.74	1.00	0.95	0.91	0.86	0.94
TH	0.16	0.63	0.61	-0.86	-0.82	0.79	0.8	0.95	1.00	0.94	0.92	0.98
Cl	0.47	0.86	0.85	-0.89	-0.85	0.81	0.75	0.91	0.94	1.00	0.98	0.96
Na	0.53	0.82	0.84	-0.96	-0.94	0.92	0.87	0.86	0.92	0.98	1.00	0.97

Table 3. Regression analysis among the various physico-chemical parameters at different sites (I-IV).

S. No.	Dependent variable (Y)	Independent variable (X)	Regression equation
1.	TDS (mg L^{-1})	EC (dS m^{-1})	TDS = 119.6 + 150.8 EC (R^2 = 0.982)
2.	DO (mg L^{-1})	BOD (mg L^{-1})	DO = 8.62 − 1.67 BOD (R^2 = 0.972)
3.	COD (mg L^{-1})	BOD (mg L^{-1})	COD = −1.32 + 4.88 BOD (R^2 = 0.956)
4.	TH (mg L^{-1})	TA (mg L^{-1})	TH = 63.4 + 0.88 TA (R^2 = 0.979)
5.	Na^+ (mg L^{-1})	Cl^- (mg L^{-1})	Na^+ = 3.12 + 0.62 Cl^- (R^2 = 0.952)
6.	BOD (mg L^{-1})	TDS (mg L^{-1})	BOD = −0.62 + 0.010 TDS (R^2 = 0.473)
7.	COD (mg L^{-1})	TDS (mg L^{-1})	COD = −4.15 + 0.047 TDS (R^2 = 0.545)
8.	DO (mg L^{-1})	TDS (mg L^{-1})	DO = 9.25 − 0.015 TDS (R^2 = 0.635)
9.	TH (mg L^{-1})	EC (dS m^{-1})	TH = 168.7 + 128.5 EC (R^2 = 0.396)
10.	Cl (mg L^{-1})	EC (dS m^{-1})	Cl = −1.84 + 24.6 EC (R^2 = 0.734)
11.	Na (mg L^{-1})	EC (dS m^{-1})	Na = −0.95 + 18.9 EC (R^2 = 0.671)
12.	K (mg L^{-1})	TH (mg L^{-1})	K = −7.21 + 0.047 TH (R^2 = 0.959)

The regression analysis of physicochemical parameters across the four sampling sites were presented in Table 3. Regression analysis provides important insights into the hydrochemical behaviour and controlling mechanisms of the studied water system. Although based on a limited number of observations (n = 4), the derived relationships highlight consistent trends that reflect both geogenic processes and anthropogenic influences. A strong positive regression between Electrical Conductivity (EC) and Total Dissolved Solids (TDS) indicates that dissolved ionic constituents are the principal contributors to conductivity. This relationship confirms that EC can be effectively used as a rapid surrogate for estimating TDS in routine water quality monitoring. The observed increase in EC and TDS from Site I to Site III suggests progressive enrichment of dissolved salts, likely due to mineral dissolution, agricultural runoff, or localized anthropogenic inputs. The inverse regression between Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) clearly demonstrates the impact of organic pollution on oxygen dynamics. As BOD increases, microbial degradation of organic matter intensifies, resulting in oxygen depletion. This trend is particularly evident at Sites III and IV, where relatively lower DO values coincide with higher BOD levels, indicating moderate organic loading and potential ecological stress.

Conclusion

The present study reveals that groundwater quality across the selected sites in Saharanpur remains within permissible limits and is generally suitable for domestic and agricultural use. The hydrochemical characteristics indicate that dissolved ionic constituents play a dominant role in controlling water quality, as evidenced by the strong positive correlation and regression between EC and TDS. Similarly, significant positive relationships among Na^-, Cl^-, K^-, alkalinity, and total hardness suggest the combined influence of mineral weathering and anthropogenic inputs. The moderate levels of BOD and COD further reflect limited but noticeable anthropogenic influence, particularly in areas exposed to industrial discharge and urban runoff. Correlation analysis highlights that organic pollution indicators (BOD and COD) are strongly associated, while their negative relationship with DO reflects oxygen depletion due to microbial activity. Regression analysis further supports these findings by demonstrating clear predictive relationships among key parameters, particularly EC–TDS, BOD–COD, and DO–BOD interactions. Although the current status indicates minimal contamination, increasing trends in dissolved ions and organic load at certain sites point toward potential future deterioration. Therefore, continuous monitoring and sustainable management practices are essential to protect groundwater quality in the face of rapid urbanization and industrial development.

DECLARATIONS

Author contribution statement: Conceptualization: S.S. and G.A.; Methodology: S.S.; Software and validation: S.S., and G.A.; Formal analysis and investigation: S.S.; Resources: G.A.; Data curation: S.S.; Writing—original draft preparation: S.S.; Writing—review and editing: S.S.; Visualization: G.A.; Supervision: S.S. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Ethics approval: This study was conducted in view of the institutional ethical guidelines and does not harm the human participants.

Consent for publication: All co-authors gave their consent to publish this paper in AAES.

Data availability: The data that support the findings of this study are available on request from the corresponding author.

Supplementary data: No supplementary data is available for the paper.

Funding statement: No external funding was received for this study.

Additional information: No additional information is available for this paper.

REFERENCES

Ali, S., Verma, S., Agarwal, M.B., et al. (2024). Groundwater quality assessment using water quality index and principal component analysis in the Achnera block, Agra district, Uttar Pradesh, Northern India. *Scientific Reports*, *14*, 5381. https://doi.org/10.1038/s41598-024-56056-8

APHA. (2023). *Standard methods for the examination of water and wastewater* (23rd ed.). American Public Health Association, Washington, DC.

Badar, M.S., Ali, S., Daniyal, Akram, M.W., Faheem, K., Khan, S.U., & Farooqi, I.H. (2024). GIS-based assessment of groundwater vulnerability to heavy metal contamination via water quality pollution indices in urban Aligarh, India. *Water Practice and Technology*, *19*(2), 419–434. https://doi.org/10.2166/wpt.2024.019

Bano, N., Shamim, S. K., Alam, M., Khalid, W., & Ahmad, A. (2026). Spatial distribution of groundwater quality from excellent to unsuitable conditions in rapidly urbanizing Firozabad city of India. *Sustainable Cities and Society: Advances*, *2*(1), 100028. https://doi.org/10.1016/j.scsadv.2026.100028N

Belal, A.A., Belal, A., Lingala, K., & Viswanath, R. (2024). Estimation of hardness level and total dissolved solids in groundwater at Shendi Town, River Nile State, Sudan. *Applied Sciences Research Periodicals*, *2*(4), 21–29. https://doi.org/10.63002/asrp.24.442

BIS. (2012). *Drinking water standards*. Bureau of Indian Standards. https://www.bis.org.in

Bhattarai, N., Lobell, D.B., Singh, B., Fishman, R., Pokhrel, Y., & Jain, M. (2023). Warming temperatures exacerbate groundwater depletion rates in India. *Science Advances*, *9*(35), 1–9. https://doi.org/10.1126/sciadv.adi1401

Bhushan, C., Patel, A. P., Kumar, A., Pandey, V. K., Kumar, P. V., Kumar, P., & Tiwari, A. K. (2025). Hydrogeochemical characterisation and human health risk assessment of groundwater in Sultanpur District, Uttar Pradesh, India. *Frontiers in Water*, *7*, 1639708. https://doi.org/10.3389/frwa.2025.1639708

Chaudhary, J. I., Ghate, S. R., Pawar, N. J., Gosavi, W. S., Chauhan, R., & Kale, S. S. (2025). Geochemical assessment of basaltic groundwater contamination in an industrial area: A case study of Ranjangaon MIDC, Maharashtra. *Next Sustainability*, *6*, 100190. https://doi.org/10.1016/j.nxsust.2025.100190

Choden, Y., Badewa, G.K., Cheki, T., & Yangzom, K. (2020). Ground water quality index of Saharanpur city, India and its spatial representation using geographical information systems. *International Journal on Emerging Technologies*, *11*(4), 157–162.

Crowther, J., Palu, A., Dunning, A., Weatherall, L., Spencer, W., Gala, D., Maganja, D., Kissock, K., Trieu, K., Young, S.L., McCausland, R., Leslie, G., & Webster, J. (2025). Global drinking water standards lack clear health-based limits for sodium. *Nutrients*, *17*(13), 2190. https://doi.org/10.3390/nu17132190

DSA, District Saharanpur Administration. (2026). *District Saharanpur, Government of Uttar Pradesh*. https://saharanpur.nic.in/

FAO. (2024). Renewable water availability per person plunges as global scarcity deepens. Food and Agriculture Organization.

Jasechko, S., Seybold, H., Perrone, D. *et al.* (2024). Rapid groundwater decline and some cases of recovery in aquifers globally. *Nature*, *625*, 715–721. https://doi.org/10.1038/s41586-023-06879-8

Karunanidhi, L.P., Subramani, D., & Srinivasamoorthy, K. T. (2021). Sources and consequences of groundwater contamination. *Archives of Environmental Contamination and Toxicology*, *80*(1), 1–10. https://doi.org/10.1007/s00244-020-00805-z

Khare, P., Agarwal, A., Vaishali, & Sharma, K. B. (2020). Assessment and minimisation of pollution level of groundwater for drinking purpose. *Journal of Emerging Technologies and Innovative Research*, *6*(6), 952–961. https://www.jetir.org/papers/JETIR1908D17.pdf

Kumar, V., Kumar, S., Srivastava, S., Singh, J., & Kumar, P. (2018). Water quality of River Ganga with reference to physico-chemical and microbiological characteristics during Kanwar Mela 2017, at Haridwar, India: A case study. *Archives of Agriculture and Environmental Science*, *3*(1), 58-63. https://doi.org/10.26832/24566632.2018.030108

Kumar, A., Bharti, D., Dutt, D., & Kumar, V. (2019). Groundwater quality assessment in River Hindon Catchment of Saharanpur, Uttar Pradesh, India. *International Journal of Agricultural and Statistical Sciences*, *15*(1), 415–421. https://www.connectjournals.com/file_html_pdf/2983601H_415-421a.pdf

Kumar, V., Saini, H., Bisht, A., Kumar, P., Bahukhandi, K. D., Kamboj, N., & Kumar, A. (2024). Impact assessment of solid waste dumping sites on soil and groundwater quality in Haridwar district, Uttarakhand, India. *Environment Conservation Journal*, *25*(3), 783-794. https://doi.org/10.36953/ECJ.27302813

Kumari, B., Keesari, T., Roy, A., et al. (2025). Comprehensive assessment of groundwater quality in the Prayagraj District, Ganga Basin. *Environmental Science and Pollution Research*, *32*, 3238–3260. https://doi.org/10.1007/s11356-024-34030-1

Mackie, P.C., Lackey, R., & Levison, J. (2022). Groundwater as a source and pathway for road salt contamination of surface water in the Lake Ontario Basin: A review. *Journal of Great Lakes Research*, *48*(1), 24–36. https://doi.org/10.1016/j.jglr.2021.11.015

Martins, G., & Mafimisebi, P. (2024). Impacts of sewage wastewater on groundwater quality and health risk in Makoko, Lagos, Nigeria. *Asian Journal of Basic Science and Research*, *6*(3), 100–110. http://doi.org/10.38177/AJBSR.2024.6312

Manna, S., Rathnam, U., Udayaraj, A., Rajesh, & Shree, T. (2024). Groundwater hardness and alkalinity as risk factors for kidney stone disease in Alwar, India: An ecological study. *Cureus*, *16*(6), e62272. https://doi.org/10.7759/cureus.62272

Maske, S. R., Markad, S. S., Ansari, F., Borkar, T. C., & Warade, H. C. (2025). Experimental analysis of water hardness and alkalinity. *International Journal of Scientific Research in Engineering and Management*, *9*(12), 1–9. https://doi.org/10.55041/IJSREM55016

Matta, G., Chauhan, A., Kumar, A., & Kumar, A. (2016). Impact of industrial effluent on groundwater and surface water quality: A case study of Dhampur region (U.P.), India. *Journal of Chemical and Pharmaceutical Sciences*, *9*(2), 709–713. https://www.jchps.com/issues/Volume%209_Issue%202/jchps%209(2)%208%20Matta%20Gagan.pdf

Matta, G., Gautam Kumar, R., Avinash, K., & Kumar, P. (2020). Suitability assessment of groundwater quality in rural areas of Haridwar District, Uttarakhand. *Pollution Research*, *39*(1), 91–96. https://www.envirobiotechjournals.com/PR/vol39i12020/Poll%20Res-17.pdf

Meghanad, U.P., Vasanthamohan, V., & Selvakumar, S. (2024). Groundwater quality assessment for drinking and irrigation: A case study in the Cauvery River Basin of Tiruchirappalli District, Tamil Nadu, India. *Water Quality Research Journal*, *60*(1), 73–88. https://doi.org/10.2166/wqrj.2024.031

Nayak, J. (2025). Assessment of Groundwater Quality at Kanpur City. *International*

Journal of Engineering Research & Technology, *14*(11), 1-8. https://doi.org/10.5281/zenodo.18074775

Sachin. (2020). Groundwater: Characteristics, pollution and treatments. *International Research Journal of Management Sociology and Humanity*, *11*(4), 224–229. https://doi.org/10.32804/IRJMSH

Sarker, B., Keya, K. N., Mahir, F., Nahiun, K., Shahida, S., & Khan, R. (2021). Surface and groundwater pollution: Causes and effects of urbanization and industrialization in South Asia. *Scientific Review*, *7*, 32–41. https://doi.org/10.32861/sr.73.32.41

Sonawane, G., Pansare, K., Patil, C., Mahajan, S., Sonawane, D., Khairnar, N., & Bhamare, M. (2024). Determination of sodium and potassium in groundwater (borewell) samples of Baglan Region of Maharashtra by flame photometry. *Asian Journal of Research in Chemistry*, *17*(6), 363–367. https://doi.org/10.52711/0974-4150.2024.00061

Sridhar, D., & Parimalarenganayaki, S. (2025). Review on urban groundwater pollution: An Indian perspective: Sources, analysis, and management strategies. *Desalination and Water Treatment*, *324*, 101453. https://doi.org/10.1016/j.dwt.2025.101453

Trivedy, R. K., & Goel, P. K. (1986). *Chemical and biological methods for water pollution studies*. Environmental Publications, India.

UCL. (2024). *Humans are depleting groundwater worldwide—but there are ways to replenish it*. https://www.ucl.ac.uk/news/2024/jan/analysis-humans-are-depleting-groundwater-worldwide-there-are-ways-replenish-it

UNESCO, United Nations Educational, Scientific and Cultural Organization. (2024). *United Nations world water development report 2024: Water for prosperity and peace*. https://www.unesco.org/en/articles/united-nations-world-water-development-report-2024-water-prosperity-and-peace

WHO. (2011). *Guidelines for drinking-water quality* (4th ed.). World Health Organization. https://www.who.int