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# The GIS framework is used to assess Lucknow City's groundwater quality using the water quality index [WQI]

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## Abstract

Monitoring groundwater quality continuously is essential to reducing the dangers of geochemical pollutants through suitable treatment techniques and guaranteeing safe drinking and irrigation. Thus, this study's main goal was to evaluate the appropriateness of the groundwater that was collected, from India's Lucknow for irrigation as well as drinking. To assess the quality of the groundwater in the research area, ten samples were taken from various locations. Analysis was done on some parameters, including pH, total dissolved solids (TDS), electrical conductivity (EC), total hardness, total alkalinity, BOD, COD, nitrate, total nitrogen, E. Coli, and ammonia. The water quality index (WQI) has arithmetical weights. Using a critical grading system that shows overall quality, the water's quality was evaluated and categorized as very good, good, moderate, bad, and unfit for consumption. Increasing public understanding and decision-making to make informed choices about efficient care, management, and long-term, sustainable social growth is greatly aided by this classification. To find relationships between the different parameter values, a correlation matrix was created and examined. As a result, the results imply that the groundwater in the investigated region is secure and appropriate for irrigation and consumption.

**Keywords:** Groundwater Contamination; Nitrates; Correlation Matrix; Water quality index; GIS.

## 1. Introduction

One of the top ten most important global dangers for the last 10 years, according to the World Economic Forum, is the depletion of freshwater supplies. If this enormous challenge is not addressed, there could be dire consequences for many sustainable goals for development (SDGs). In 89 countries, the majority of the water bodies that were evaluated had serious pollution. A list of the world's most polluted rivers includes the Ganges (1). The Cita Rum River in Indonesia is the second most polluted river in the world. In a similar vein, the Yellow River in China now has the title for the fastest modernization. Both the shaping of the land and the regulation of the climate are greatly influenced by water (2). It is one of those natural resources that affect entire ecosystems critically. Groundwater is now as important as ever (3). This has negative effects on the ecosystem that have an impact on groundwater supplies' long-term viability. The majority of Indians get their drinking water from groundwater. The availability and quality of groundwater reservoirs are significantly impacted by human activities, such as overuse and inappropriate disposal of waste from industrial, agricultural, and domestic sources [4].

Environmental pollution poses a grave threat to the delicate balance of ecosystems and human health, with wastewater being a significant contributor. Wastewater, laden with various pollutants from industrial, agricultural, and domestic sources, when discharged untreated into water bodies contaminates aquatic habitats and endangers aquatic life. Additionally, it poses serious health risks to humans through the consumption of contaminated water and seafood.

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Therefore, the necessity of wastewater treatment cannot be overstated. Treatment processes like filtration, biological degradation, and chemical treatment are essential to remove harmful contaminants, pathogens, and nutrients from wastewater before its release back into the environment. Proper wastewater treatment not only safeguards human health but also preserves the integrity of ecosystems, ensuring the sustainability of vital natural resources for future generations (5).

The quality of groundwater is deteriorating, endangering human health as well, and treating several waterborne illnesses has become quite costly. In several regions of the country, the quickening rate of industrialization, urbanisation, and agricultural expansion has also resulted in the overuse and contamination of groundwater supplies [6].

With a high score, the Gomti River is the third unclean river in the world. Unfortunately, many countries still do not routinely gather data on the quality of their water, endangering the lives of more than three billion individuals' freshwater ecosystems are unknown. Maintaining the environment and providing safe water is one of the most important responsibilities of all people on the planet [7].

Groundwater is an essential resource for maintaining ecosystems and supplying human needs, but it needs to be carefully monitored and evaluated to make sure it is suitable for a range of uses. Monitoring groundwater quality is critical to preserving human health and environmental sustainability. But taking into account that conventional methods to determine groundwater quality usually have disadvantages and imperfections more advanced and useful techniques are required (8).

Standard methods are used to test water samples in the laboratory to determine particular characteristics such as pH, turbidity, and concentrations of chemicals. These techniques can be labour-intensive and expensive in terms of supplies with little return on investment, but they offer important information about certain aspects of groundwater quality. Moreover, their inability to acknowledge the intricate interrelationships and geographical variations present in groundwater systems could prevent an accurate assessment of the trends in overall water quality (9).

To correctly assess groundwater quality in this situation, the index for water quality (WQI) might be used. The quality of groundwater at multiple sites within a single area, such as Lucknow city in this study, can be extensively assessed thanks to GIS's potential to provide spatial evaluation and presentation of numerous parameters [9].

The Water Quality Index (WQI), which offers an impartial and impartial rating of whole water quality, makes it easy to integrate doubles indicator values for water quality into one measurement. WQI scores can be used to quickly identify the intensity of water contamination as well as whether groundwater samples are adequate for industrial and drinking use. Additionally, by comparing groundwater quality to national necessities, WQI helps legislatures and other interested parties to identify problem areas and determine methods of intervention [10].

Our study's objective is to shine a light on our specific comprehension of Lucknow city's groundwater supply by evaluating the potentially harmful elements of drinking water samples. Using a GIS framework and the WQI procedure, our objective is to conduct a comprehensive assessment of groundwater quality that takes into account human and natural variables [11].

In general, by overcoming the expertise gap between recently developed GIS-based procedures and firmly established groundwater quality assessment methods, this research project aims to provide insights into an evaluation of groundwater quality in Lucknow city. Our goal is to provide helpful recommendations to improve methods of monitoring and regulating water quality through deep analysis and comprehension of spatially specified data. [12].

The main goal of this research is to use a WQI and GIS to assess whether groundwater is appropriate for consumption by humans. Ten groundwater samples extracted through hand pumps and tube wells have undergone a physicochemical examination. Using the WQI for domestic and drinks and contrasting it with global standards set by the BIS and WHO. Its foundation is weighted arithmetic calculation. Many academics have put forward many models for the water quality index (WQI), all of which are based on the weighted arithmetic look to evaluate and balance varying water quality requirements. Numerous scholars have proposed various models for the water quality index (WQI) that utilise the weighted arithmetic methodology for evaluation[13]. The Water Quality Index (WQI) is a unique numerical ranking that shows the overall condition of the water quality measurement based on multiple water quality variables. It has classifications like good, poor, very poor, moderate and unfit for drinking at a certain time and place.

Its value options go from 0 to 100. For this reason, the WQI is a crucial tool for evaluating and controlling groundwater quality in every particular area. It also helps identify suitable and economically feasible therapies for excellence-related problems. It offers legislative decision-makers and the general public with information on water quality, enabling them to implement strict regulations and carry out activities related to water quality [14].

The purpose of this paper is to: (a) assess the groundwater quality in the research area and provide an interpretation of it; and (b) determine whether it is suitable for irrigation and drinking in the area.

## 2. Methods and materials

### 2.1. Study area

Uttar Pradesh's capital city, Lucknow, is roughly 2528 km$^2$ in size and is located between 26°300 a N latitude and 81°120 E longitude. The Gomti River traverses the city's core. The estimated population of Lucknow, the capital city, is 4,589,838. This region's Quaternary sedimentary deposits are separated into two categories: old and new alluvial deposits. The former is primarily made up of sand, silt, and clay without any kankar (little pebbles), while the latter is made up of Grains of sand, silt, and clay ranging from fine to coarse. Hand pumps and bore wells served as the sources of ground water for the samples. Sampling bottles were used to gather the samples. Numerous physico-chemical parameters, including pH, conductivity, total dissolved solids (TDS), alkalinity, total hardness, and nitrate nitrogen ($NO_3$), were examined in the collected samples. All of these parameters were examined in accordance with standard procedures for the examination of water and wastewater. Fig. 1 and Table 1 show the study area and sampling location of the research paper.

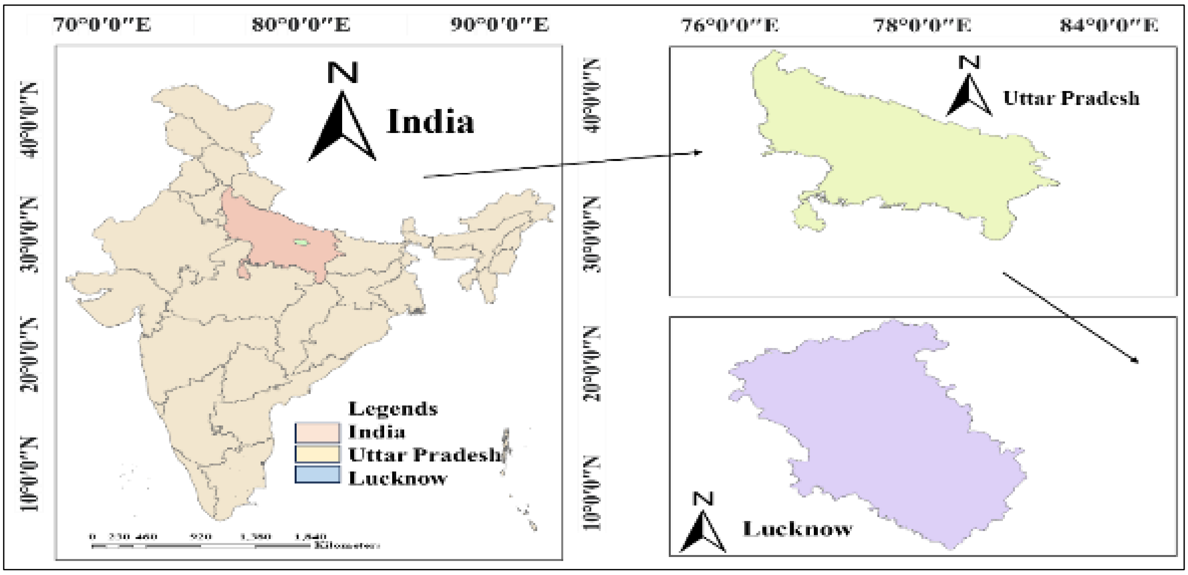



**Figure 1** Location map of the study area

**Table 1** Location Points

| S. No. | Locations |
|---|---|
| 1 | River front Gomtinagar |
| 2 | Near Janeshwar Park, Gomtinagar |
| 3 | ChhathGhat, R297+8JG, AmarShaheed Path, Sector 1, Gomtinagar |
| 4 | Pipraghat, Neil Lines, Cantonment, Lucknow, Uttar Pradesh |
| 5 | Near Baikunthdham, butler colony |
| 6 | Hanumansetu, Babuganj, Hasanganj |
| 7 | Near Gautambhudh Park, VW9C+PH5,Biratnagar, Hasa |

| | |
|---|---|
| 8 | VWF6+MF6, KudiyaGhat Rd, Husainabad |
| 9 | Gulalaghat, 538B, 05 /016B, Shivnagar Rd, Rooppur, K |
| 10 | MehandiGhat, Durgadevi Rd, Husainabad |

### 2.2. Sampling and Methods

Ten groundwater samples were taken using normal procedures from ten different regional stations. The research area's groundwater chemistry was precisely represented by the samples that were taken from boreholes, hand pumps, and tube wells, which represented both shallow and deep aquifers. All around the study area, sampling stations were dispersed uniformly. To avoid any possible contamination and consequent changes to the properties of the groundwater, one-litre capacity bottles composed of High-density polyethene (HDPE) were sterilized using aseptic procedures [15]. For physio-chemical analysis, the samples were taken to a chemical laboratory in Lucknow and kept in a transportable ice box. The samples were kept at 4–5 ∘C in the chemical laboratory. Using accepted techniques, all ten samples' eleven groundwater quality metrics were examined. A pH meter and turbidity meter were used to measure the unstable parameters namely turbidity and pH. To calculate TDS, the gravimetric approach are used. COD, BOD, electric conductivity, total alkalinity, and total hardness were measured by volumetric titrations in the analysis. While nitrate concentrations were measured using ion-selective electrode technology and UV screening, respectively. We employed the ICP-MS technique to Data quality assurance and control procedures were carefully taken into account in the study mentioned in Table 2.

**Table 2** Specifics of the instruments utilised analysis techniques, and physio-chemical parameters examined.

| S. No. | Parameter | Often used as | Method | Instrument |
|---|---|---|---|---|
| 1 | Electric conductivity | EC | AC | Spectroscopy |
| 2 | pH | pH | Electrometric method | pH meter |
| 3 | Total dissolve solid | TDS | Gravimetric | Electronic balance hot, air, oven |
| 4 | Total suspended solids | TSS | Gravimetric | - |
| 5 | Alkalinity as $CaCo_3$ | T Alk | Titrimetric | - |
| 6 | Total hardness | T Hardness | Titrimetric | - |
| 7 | Nitrate | $NO_3$ | UV Screening | Spectro photometer |
| 8 | Ammonia | $NH_3$ | UV Screening | Spectro photometer |
| 9 | BOD mg/l 5 days 20°C | BOD | - | Benchtop instruments |
| 10 | COD | COD | - | Proteus Multiparameter COD Sensor |

### 2.3. Water Quality Index (WQI)

The WQI was calculated for six parameters in this study. Based on drinking water quality standards established by the World Health Organization, the Bureau of Standards of India (BIS), and the Indian Council for Medical Research, the WQI was calculated. The following sequential stages were used in the weighted arithmetic index approach to calculate the WQI for water [16].

### 2.4. Weightage Factor (Wi)

The weights (wi) of the criteria were assigned according to how crucial they are to maintaining water quality. The following method was used to determine the weightage factor.

$$Wi = wi / \sum in = Wi \qquad \text{(i)}$$

where Wi Indicates relative weight, wi Indicates the weight of every parameter and n

Indicates the number of parameters tested.

### 2.5. Calculation of Sub-Index (Qi)/Quality Rating

The calculation of the sub-index is as follows:

$$(\text{Sub–index})\ Qi = (Ve - Vi)/(Vs - Vi) \times 100 \qquad \text{(ii)}$$

where Ve indicates an expected value for the ith parameter, Vi Indicates an ideal value for ith parameter, V indicates a standard permitted value for the ith parameter and Qi Indicates the quality rating for the ith water quality parameter.

### 2.6. WQI calculation

First calculating WQI, each parameter's sub-index must be calculated using the following formula:

$$SIi = wi \times qi \qquad \text{(iii)}$$

Where n denotes the parameter numbers, SIi denotes the sub-index of its parameter, and qi is the sub-rating based on its concentration of it. To determine the Overall WQI, the values of each groundwater sample's sub-index were summed. WQI = ∑SIi Calculated values of WQI were classified into five different categories: very good, Good, poor, very poor, and unfit for drinking (16) .

### 2.7. Parameters of Ground Water Quality

#### *2.7.1. Concentration of (pH)*

The pH range in this study was 7.02 (lowest) to 8.15 (highest), which is within the permissible range and shows how alkaline the groundwater is (6.5–8.5) is the recommended pH range for drinking purposes).

#### *2.7.2. Total Dissolved Solids (TDS)*

TDS in this investigation varied from 312 to 1145 mg/L (safe water is defined by BIS as being <500 mg/L). The primary sources of TDS of point pollution that are released by industry or sewage treatment plants include cultivation practices, soil leaching, urban runoff, and sources.

#### *2.7.3. Total Alkalinity*

It is permissible for drinking water to have up to 200 mg/l of alkalinity; much more than that and the water starts to taste harsh. Alkalinity in this study ranged from 120 to 440 mg/l, which is within the permissible limits of 200 mg/l.

#### *2.7.4. Total Hardness*

The permitted range (200 mg/l) for the hardness of the water utilised in this experiment is between 128 and 456 mg/l. Elevated levels of hardness in groundwater can lead to heart problems and kidney stones.

#### *2.7.5. Nitrate ($NO_3$)*

An essential component of the nitrogen cycle, nitrate is a naturally occurring ion. However, as it can result in methemoglobinemia in infants younger than six months old, nitrate in groundwater poses a concern. In general, elevated nitrogen concentrations above There is a health risk within the allowed range of 45 mg/l. The current investigation shows that the allowed range of nitrate concentrations is exceeded, ranging from 7.60 to 18.50 mg/l. Pregnant women and newborns are more vulnerable to health problems when drinking water has high nitrate concentrations 45 Electric conductivity (EC) ranges 574-1874 us/cm will be obtained from this study location (17).

IS 10500 Water Quality Based on WQI Category

- 0-25 Excellent
- 26-50 Good
- 51-75 Poor
- 76-100 Very poor
- 100 Unfit for consumption

## 3. Results and discussion

The samples were kept in the chemical laboratory at 4 and 5 ∘ C. All ten samples' results shown in table 3.

**Table 3** Lab test results

| S. No. | TEST | Result (Pipra Ghat) | Result (Gautam Buddha Park) | Result (Mehandi Ghat) | Result (Gulala Ghat) | Result (Kudiya Ghat) | Result (Chhath Ghat) | Result (Gomti River Front) | Result (Janeshwar Mishra Park) | Result (Baikunth Dham) | Result (Hanuman Setu) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | EC | 1875.00 | 1139.00 | 594.00 | 1423.00 | 900.00 | 933.00 | 748.00 | 574.00 | 929.00 | 1209.00 |
| 2 | pH | 7.83 | 7.24 | 7.74 | 7.72 | 7.02 | 7.32 | 8.15 | 7.82 | 7.23 | 7.19 |
| 3 | TDS | 1145.00 | 645.00 | 312.00 | 867.00 | 545.00 | 744.00 | 424.00 | 317.00 | 694.00 | 761.00 |
| 4 | TSS | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 5 | Alkalinity as CaCO3 | 440.00 | 288.00 | 140.00 | 320.00 | 204.00 | 268.00 | 160.00 | 120.00 | 228.00 | 320.00 |
| 6 | Total Hardness as $CaCO_3$ | 456.00 | 296.00 | 156.00 | 332.00 | 216.00 | 276.00 | 168.00 | 128.00 | 244.00 | 324.00 |
| 7 | Nitrate Nitrogen as $No_3$ | 18.50 | 9.25 | 7.60 | 13.20 | 9.13 | 7.60 | 11.10 | 8.00 | 12.20 | 15.60 |
| 8 | Ammonia as $NH_3$ | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 9 | Biological Oxygen Demand as BOD (mg/l) 5 days at 20 C | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 10 | Chemical Oxygen Demand COD | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 11 | Total Nitrogen as N | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL |
| 12 | E-coli | Absent | Absent | Absent | Absent | Absent | Absent | Absent | Absent | Absent | Absent |

**Table 4** Correlation Matrix of parameters with groundwater quality

| | EC | PH | TDS | Total alkalinity | Total hardness | Nitrate |
|---|---|---|---|---|---|---|
| EC | 1 | | | | | |
| PH | -0.0346 | 1 | | | | |
| TDS | 0.95595 | -0.15531 | 1 | | | |
| Total Alkalinity | 0.974071 | -0.16728 | 0.972804 | 1 | | |
| Total hardness | 0.97741 | -0.16085 | 0.975997 | 0.999089 | 1 | |
| Nitrate | 0.842027 | 0.114701 | 0.79063 | 0.793853 | 0.796155 | 1 |

As shown in Table 4, groundwater quality parameters were evaluated for general statistical analysis and the tabulation of the correlation matrix. A correlation matrix comprising six distinct factors was produced. Of the six variables, total hardness, alkalinity, and electrical conductivity all have negative correlations with each other, while pH and TDS have positive correlations. There is a positive link between the maximum quality parameters. For the region's groundwater quality in the future, they need to be closely observed.

**Table 5** The category and water quality index for each station in the research region

| Location | Sample code | Source of sample | Value of WQI | category |
|---|---|---|---|---|
| Pipraghat | 1 | Hand pump | 100.17 | Unfit for drinking |
| Gautumbudha park | 2 | Hand pump | 82.71 | very poor |
| Mehandi ghat | 3 | Tube well | 79.43 | very poor |
| Gulala ghat | 4 | Hand pump | 91.43 | very poor |
| Kudiya ghat | 5 | Tube well | 77.39 | very poor |
| Chhath ghat | 6 | Tube well | 82.61 | very poor |
| Gomti riverfront | 7 | Tube well | 85.88 | very poor |
| Janeshwar Mishra park | 8 | Tube well | 79.74 | very poor |
| Baikunth Dham | 9 | Hand pump | 82.02 | very poor |
| Hanuman Setu | 10 | Tube well | 86 | very poor |

Table 5 and Fig. 2 show WQI variation in the study locations. The acid-base balance of water is measured by its pH level. Depending on its pH level, water can be classified as acidic, neutral, or alkaline. Extremely high or low pH water is dangerous to consume and should not be used for certain purposes. The WHO, or World Health Organization, recommends keeping the pH in the range of 6.5 to 8.5. When people use water with a pH higher than 10, it can irritate their skin, eyes, and mucous membranes. It may also result in gastric irritation and the swelling of hair fibres. On the other hand, employing water with a low pH has comparable consequences and reduces the effectiveness of disinfection.

Observed a high pH of 8.25 in the district of Lucknow. The pH range in the current study was 7.32 to 8.25.

All dissolved mineral components and other particles in water are collectively referred to as total dissolved solids or TDS. TDS is a measure of how well water is suited for various uses. Water deemed appropriate for drinking is defined as having TDS levels less than 500 $mgL^{-1}$. Increased TDS Values affect the taste, hardness, and corrosive properties of water. When the concentration of TDS is more than 1000 $mgL^{-1}$, the water loses its taste for human consumption 200 $mgL^{-1}$ was found to be the peak TDS level in the Lucknow district. TDS fluctuated in the current investigation between 300 and 1090 $mgL^{-1}$, over the allowable limit.

The term "alkalinity," which also refers to a water's buffering capability, describes its capacity to neutralize the acid. People with diabetes, high blood pressure, and high cholesterol may benefit from slightly alkaline water.

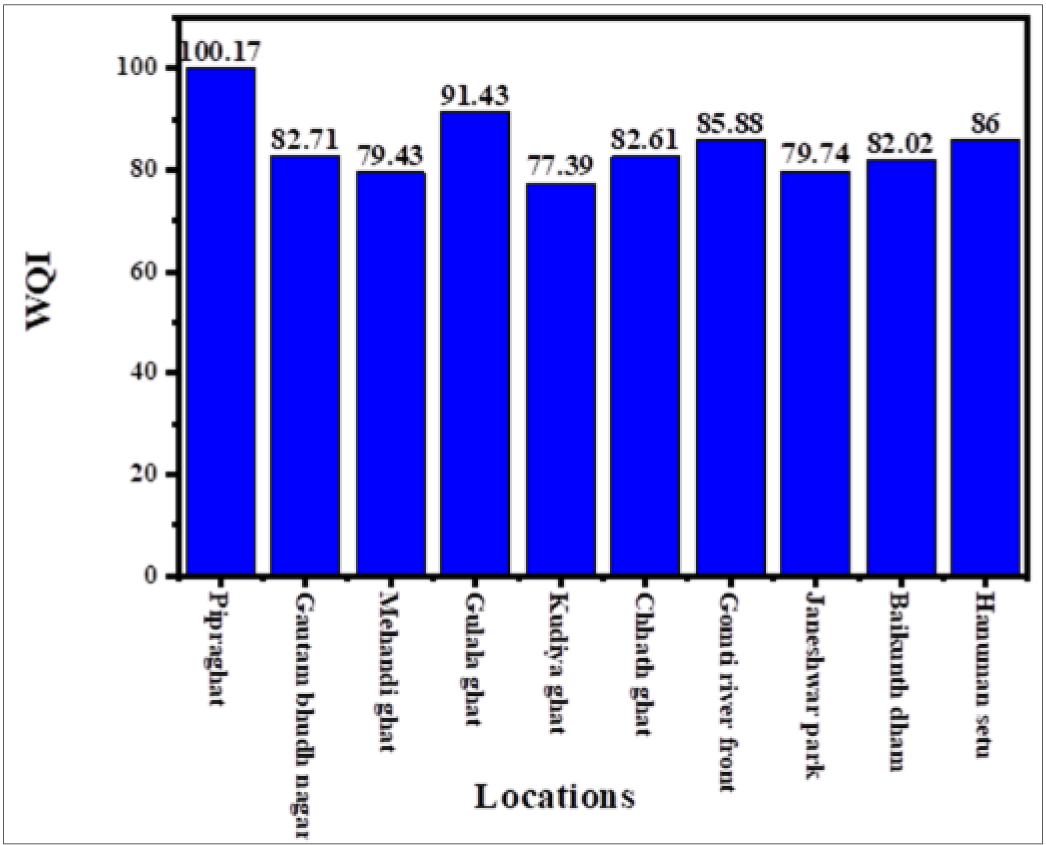



**Figure 2** WQI for study location

Benefits include potential resistance to cancer and weight management. Prolonged ingestion of excessively alkaline water, however, may have negative side effects, such as nausea, vomiting, skin irritation, and muscle spasms, especially in the vicinity of the face extremities.

High levels of hardness can affect several things, such as water supply systems, overuse of soap, and the risk of artery calcification. Urinary concretions, renal and bladder disorders, and gastrointestinal disorders may be exacerbated by these consequences

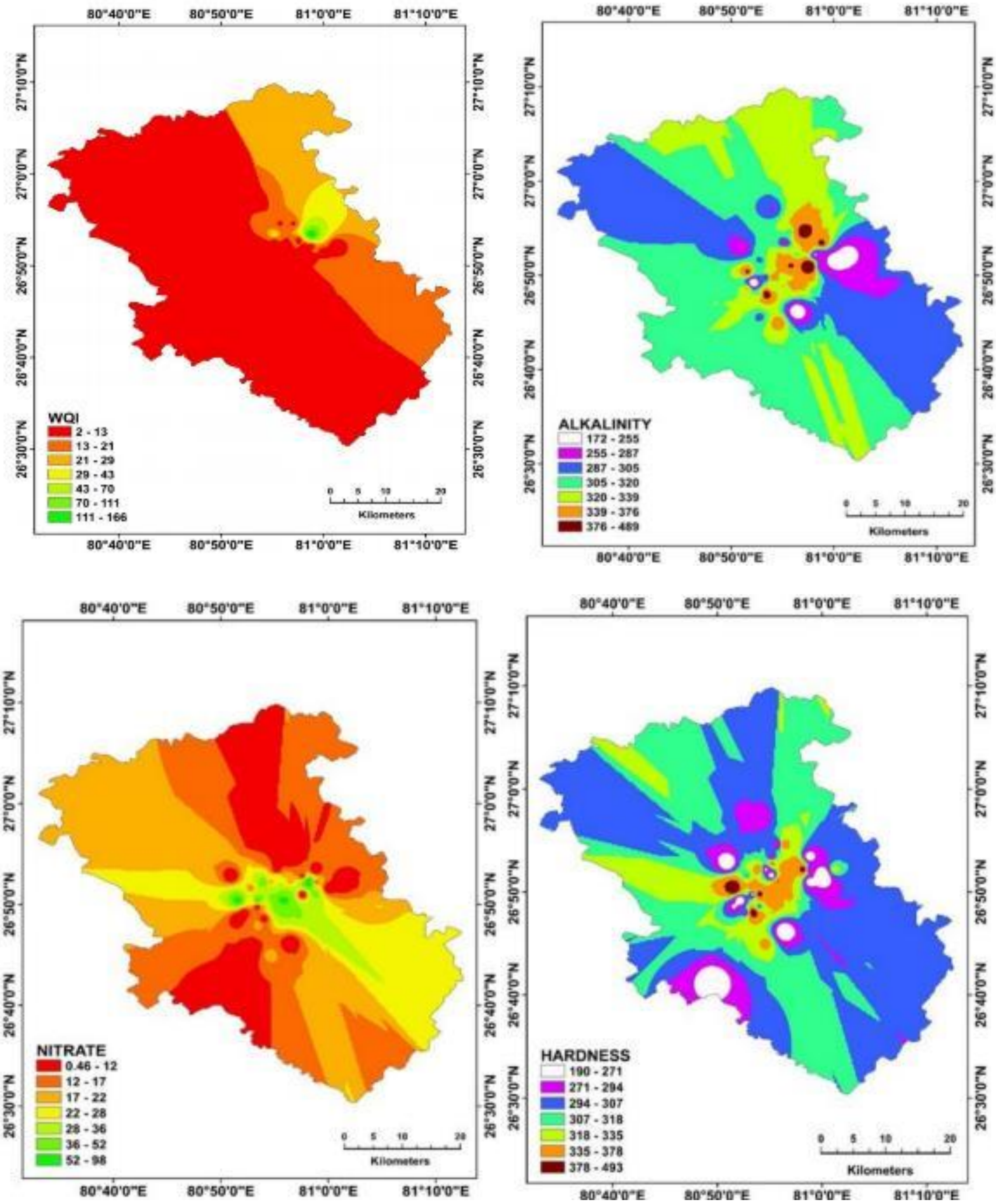
One naturally occurring ion connected to the nitrogen cycle is nitrate. Overindulging in nitrates can result in thyroid issues and "blue baby syndrome." Groundwater contamination by nitrate is a worldwide problem that is frequently linked to farming practices. In India, the permissible level of 45 $mgL^{-1}$ is exceeded by nitrate concentrations in 11 out of 28 states.

The maximum amount of nitrate allowed in drinkable water, according to Indian guidelines, is 45 $mgL^{-1}$. Revealed that Lucknow had a maximum nitrate content of 15 $mgL^{-1}$.

BOD, COD, ammonia, TSS, and total nitrogen are found below the detection limit (BDL). E-coli are also absent in all study locations.

### 3.1. Spatial distribution

In Figure 3, the pH ranged from 7.32 (lowest) to 8.25 (highest) in this study, indicating the alkalinity of groundwater and falling within the acceptable range (6.5–8.5 is the optimal pH range for drinking reasons). Turbidity is the term used to describe the cloudiness of water caused by suspended particles such as silts, clay, organic materials, and chemical precipitates (such iron and manganese). Increased turbidity reduces the clarity of water by dispersing and absorbing light that is transmitted. All dissolved mineral components and other particles in water are collectively referred to as total dissolved solids, or TDS. TDS is a measure of how well water is suited for various uses. TDS concentrations less than 500 $mgL^{-1}$ are regarded as safe for drinking water. TDS fluctuated in the current investigation between 312 and 1145 $mgL^{-1}$, which is higher than allowed. Alkalinity, another name for buffering capacity, is the measure of an acid's ability to be neutralised by water. People with diabetes, high blood pressure, and high cholesterol may benefit from slightly alkaline water. The study's alkalinity ranged from 120 to 440 $mgL^{-1}$, staying well under the 600 $mgL^{-1}$ permissible limits. High levels of hardness can affect a number of things, such as water supply systems, overuse of soap, and the risk of artery calcification. Urinary concretions, renal and bladder problems, and gastrointestinal issues may be made worse by these consequences.



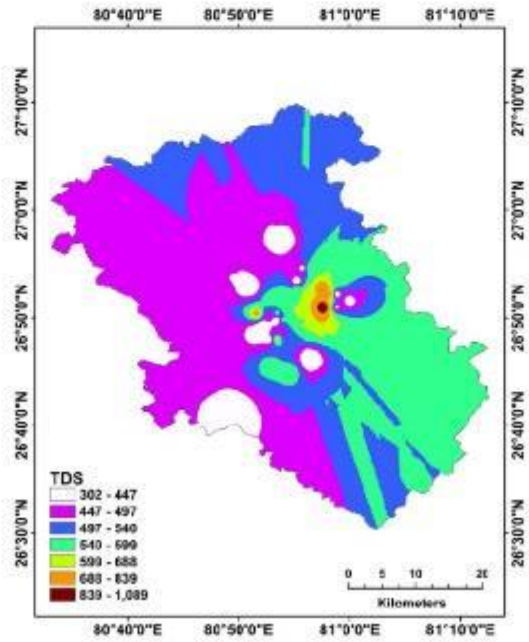



**Figure 3** Spatial variation WQI, Alkalinity, Nitrate, Hardness, and TDS across the study area

*Abbreviation*

| | |
|---|---|
| WQI | Water quality index |
| BOD | Biological oxygen demand |
| COD | Chemical oxygen demand |
| EC | Electrical conductivity |
| pH | Potential of hydrogen |
| TDS | Total dissolve solid |
| TSS | Total suspended solids |
| TH | Total hardness |
| GIS | Geographic information system |

## 4. Conclusion

The results of this study show that the groundwater quality in Lucknow's flat alluvial zone is often very poor. From a hydrogeological perspective, the multi-layered aquifer system formed by the thick Quaternary deposits is regarded as one of the best. An excellent water flow is made possible by this configuration, improving the quality of the groundwater. However, it has been observed that unsustainable human activities have increased groundwater nitrate concentrations, especially in the north-central portions of the research area. These include the use of synthetic nitrogen fertilisers, combustion engines in cars, spreading sludge on fields to dispose of municipal effluent, atmospheric emissions from the energy production industry, septic tanks, leaking sewage systems, inadvertent releases of nitrogen-rich compounds, and using sound injection techniques to dispose of waste that contains a lot of nitrogen. The quality of water supplies is significantly impacted in densely populated metropolitan areas, mostly as a result of increased industrial, human, and agricultural activities. There have been reports of high pH in the Gomti riverfront region, and in certain places, alkalinity levels have exceeded allowable limits. The groundwater in the remaining places is safe and drinkable, as shown by their reduced WQI readings, guaranteeing safe drinking and household water quality. Based on WQI, the analysis conducted for this study concluded that the area's groundwater is safe to drink.

## Compliance with ethical standards

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### *Disclosure of conflict of interest*

All contributors declare that no relationships of interest occur.

### *Statement of ethical approval*

The author disclosed that there is no human or animal heart in this study.

### *Authors Contributions*

Arpit Verma: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing, Validation, Software investigation. Hrishikesh Kumar Singh: Supervision, Validation, Visualization, Writing – review & editing, Conceptualization. Vipin Kumar: Software validation Writing – review & editing.

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### *Data Availability Statement*

New data were created or analyzed during this study.

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