JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Groundwater Quality Assessment in Panchkula District, Haryana, India

[1]Deepika Sain, [2]Dr. Arpna, [3]Dr. Jai Pal
[1,2]Department of Chemistry, Baba Mastnath University, Asthal Bohar, Rohtak, Haryana, India
[3]Department of Chemistry, S.D College Ambala Cantt, Haryana, India

Abstract: Continuous groundwater quality monitoring is crucial for ensuring safe drinking and irrigation by mitigating risks from geochemical contaminants through appropriate treatment methods. Therefore, the primary objective of this study was to assess the suitability of groundwater collected from Panchkula District, Haryana India, for both drinking and irrigation. Many samples were collected from different sites within the study area to evaluate groundwater quality. Various parameters such as pH, turbidity, EC (electrical conductivity), total dissolved solids (TDS), chlorides (Cl^-), total alkalinity, total hardness, sulphate ($SO^{2-}{}_4$), nitrate (NO_3^-), fluorides (F^-), arsenic (As), Iron (Fe), lead Cd, and chromium were analyzed. The weighted arithmetic water quality index (WAWQI), a vital rating system representing overall water quality, was employed to classify the water into different categories, such as very good, good, moderate, poor, and unfit for drinking. This classification is invaluable for public awareness and decision-making to make informed decisions regarding effective management, treatment, and sustainable societal development on a broader scale. A correlation matrix was generated and analyzed to observe correlations between the various parameters. Additionally, spatial distribution maps for the analyzed parameters and WQI were prepared using the inverse distance weighted (IDW) method. The study found that WQI values in the area ranged from 0 to 50, indicating good water quality in most places for drinking purposes. The water quality map shows that 40% of the area falls under the very good category, and 60% is categorized as unfit for drinking. Consequently, the findings suggest that the groundwater in the studied area is safe and suitable for drinking and irrigation purposes.

Index Terms - **Groundwater contamination; arsenic; nitrate; water quality index; geographical information system.**

I. INTRODUCTION

One of the top ten most important global risks for the last ten years according to the World Economic Forum is the depletion of freshwater resources. If this enormous challenge is not addressed there could be dire consequences for many of the Sustainable Development Goals (SDGs) [1]. In 89 countries the majority (more than 40%) of the water bodies that were evaluated had severe pollution [2]. The Ganges River has been named the most polluted river in the world and 80% of Indias water resources are considered degraded. Due to the significant influence of human settlements the Citarum River in Indonesia is the second most polluted river globally. Likewise, the Yellow River in China is the third dirtiest river in the world a status that is a result of rapid industrialization [3]. The health of over 3 billion people's freshwater ecosystems is unknown which puts them at risk as water quality data collection is sadly still rare in many countries [4]. One of the most important duties of all peoples worldwide is to preserve the environment and the quality of the water [5]. Global urbanization is contributing significantly to the quality of water as pollutants from diverse sources end up in large bodies of water [6]. Both giving the land its shape and controlling the climate are important functions of water. It is one of those natural resources that affects entire ecosystems in a major way. Groundwater resources particularly those associated with rapid urbanization and industrialization are under increasing pressure leading to a multiplex increase in the need for groundwater. The various waterborne diseases that are caused by the deteriorating quality of groundwater have resulted in substantial expenses for treating the public health risks. Because of overuse and pollution of groundwater resources the country rapid industrialization urbanization and agricultural growth rate have also led to groundwater pollution in a number of areas. This has negative effects on the environment that have an impact on groundwater resources long-term sustainability. Indias groundwater supply is vital to a large section of the population [7]. Groundwater reservoir availability is negatively impacted by human activities such as overuse and inappropriate disposal of waste from industrial agricultural and residential sources as well as caliber [8-10]. Hence cultivation methods generally especially those involving the use of excessive fertilizer unsanitary conditions and the discharge of pose a risk to human health. sewage into the ground [11]. Seasons depth the subsurface environment and dissolved salts that have leached all affect groundwater quality [9-12]. Nearly 80% of human diseases are spread through water according to the World Health Organization [13]. If groundwater is contaminated once it becomes extremely difficult to restore the water quality. Finding strategies to stop pollution and conducting routine groundwater quality monitoring are therefore essential. The chemical physical and biological qualities of groundwater have all been examined [14]. The data on groundwater quality are essential for handling and evaluating analytical determination values and determining the quality of a water resource. The principles of WQIs make the classification of groundwater much more feasible [15–20]. Mathematical techniques called water quality indices (WQIs) are used to categorize water quality [21, 22]. They play a vital role in condensing and streamlining diverse analytical determination values that represent the quality of a water resource [23, 24]. The quantity and quality of water are closely related to socioeconomic development. The primary components of water quality indicators are sub-indicator development and aggregation functions. Under various environmental requirements a water quality index (WQI) depicts the overall state of water. Groundwater quality monitoring and assessment have been conducted on a regular basis with the use of IDW interpolation techniques in conjunction with geographic information system (GIS) techniques. These are strong instruments that have been developed recently for exploring and evaluating spatial data about water resources [18, 25–29]. By transforming large datasets to create a variety of projections and spatial distribution maps it is a quick and cost-effective way to illustrate the relationships sources and trends of groundwater pollution. The spatial analysis of various groundwater parameters was done in this work using GIS technology. The main goal of this research is to determine whether groundwater is suitable for human consumption by utilizing a WQI and geographic information systems (GISs). The WQI for drinking and household use was used to analyze and compare the physicochemical characteristics of forty groundwater samples taken from tube wells and hand pumps to international standards established by BIS and WHO. Horton first proposed the WQI in 1965 [30] and it is based on a weighted arithmetic computation. Different WQI models have been proposed by several researchers [31–36] based on the weighted arithmetic methods rating and weighing of different water quality parameters. Based on several water quality parameters the WQI is a unique numerical rating that expresses the overall state of the water quality. It shows categories such as very good, good moderate poor and unfit for drinking at a given time and place. It can have values ranging from 0 to 100. Thus a vital tool for assessing and controlling groundwater quality in any given area is the WQI [37]. It also helps in choosing treatment procedures that are both appropriate and economically feasible in order to address quality-related problems. It provides legislative decision-makers and the general public with information on water quality in order to support the implementation of stringent policies and water quality-related programs [16,18,20,38]. This paper aims: (a) to investigate and interpret the groundwater quality in the study area and (b) to evaluate its suitability for drinking and irrigation purposes in the region.

II. STUDY AREA

Panchkula District located between 30º 26'–30 º 55' North and 76º 46'–77 º 10' East is in the northern region of the state of Haryana. The district is bordered to the north by Himachal Pradesh to the east by Uttar Pradesh to the west by Ambala District and to the south by Karnal District. The district occupies 882.92 sq. km in total (Figure 1). The four development building blocks of Pinjore Barwala Raipur Rani and Morni make up the district of Panchkula along with two tehsils. With 522 people per square kilometer Panchkula is a densely populated district with a population density higher than the state average of 478 people per square kilometer. The region is mostly drained by the Ghaggar River and its affluents. It is possible to classify the climate of Panchkula as subtropical monsoon mild and dry winters and hot summers. The Siwalik Hills lie along the districts northeast and northwestern frontages rising to a maximum elevation of 950 meters above mean sea level. The district receives 1057 mm of rainfall on average each year. Regarding the adjacent alluvial plains, the hills rise to a height of about 500 meters. Their distinctive feature is the vast area of terrain that numerous transient streams have sculpted into relatively steep slopes resulting in the dispersal of numerous gravel stones along the streams beds. These streams descend to the outer slopes of the Siwalik Hills.

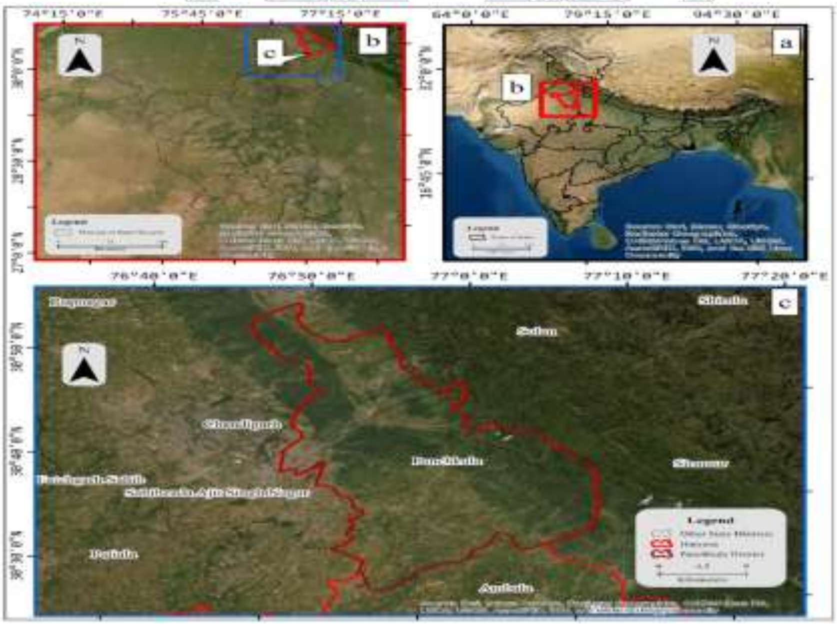

Figure 1. Location map: (**a**) the location of the state of Haryana in relation to India (red square); (**b**) the location of Panchkula District with respect to the state of Haryana (blue square); (**c**) the location of Panchkula District along with neighboring districts of other states. The map coordinates are in the UTM 43 (North)World Geodetic System (WGS-1984) reference system.

III. MATERIALS AND METHODS

Samples of groundwater have been taken at a number of unique regional stations. Before being delivered to a state-level water analysis laboratory for physio-chemical analysis the samples were kept cold in a portable ice box. The samples were kept between 4-5 ºC in the chemical laboratory. Standard procedures were used to analyze the groundwater quality parameters of each sample. Using a pH meter and a turbidity meter the unstable parameters turbidity and pH were measured. To calculate TDS, the gravimetric approach was utilized. Chloride total alkalinity and total hardness were measured using volumetric titrations in the analysis. While nitrate and fluoride concentrations were determined by ion-selective electrode technology and UV screening respectively sulphate levels were evaluated using the turbidimetric method. ICP-MS was used to analyze the levels of iron and arsenic (Table 1).

Table 1. Details of analyzed physio-chemical parameters, and instruments used.

Parameter	Abbreviation	Instrumentation/Technique
Ph	pH	Digital pH meter (Hanna HI 2211)
Electrical Conductivity	EC	Digital conductivity meter (Hanna HI 8733)
Total dissolved solids	TDS	Calculation from EC
Total Hardness	T-Hard	EDTA titrimetric method
Total Alkalinity	T- Alk	Titration method
Chloride	Cl^-	Argentometric titration method
Sulfate	$SO^{2-}{}_4$	Turbidimetric method
Fluoride	F^-	Ion-selective electrode method
Nitrate	NO_3^-	Cadmium reduction method
Iron	Fe	Phenanthroline method
Heavy Metals (As, Pb, Cr)	As, Pb, Cr	Atomic absorption spectrophotometry (graphite furnace)
Chemical Oxygen Demand	COD	Open reflux method
Biological Oxygen Demand	BOD	5-day BOD test

Table 2. Statistical analysis of analyzed physio-chemical parameters of groundwater quality in the study area.

Parameters	Unit	BIS	Min.	Max.	Mean	SD
Ph	On Scale	6.5-8.5	6.5	8.2	7.3	0.4
EC	(µS/cm)	1500 µS/cm	250	3500	1200	800
TDS	(mgL^{-1})	500–1500	160	2240	768	512
Cl-	(mgL^{-1})	250-700	20	1000	200	240
Total alkalinity	(mgL^{-1})	200-600	100	800	360	200
Total hardness	(mgL^{-1})	200-600	120	1200	480	280
($SO^{2-}{}_4$)	(mgL^{-1})	200-400	10	500	120	120
(NO_3^-),	(mgL^{-1})	45	2	200	40	48
(F^-)	(mgL^{-1})	1–1.5	0.2	5.0	1.2	1.0
Fe	(mgL^{-1})	0.3–1.0	0.05	5.0	0.8	1.0
As	(mgL^{-1})	0.01–0.05	0.001	0.05	0.01	0.01
Pb	(mgL^{-1})	0.01–0.05	0.001	0.03	0.002	0.006
Cr	(mgL^{-1})	0.01–0.05	0.001	0.05	0.01	0.01

Table 3. Correlation matrix of groundwater quality parameters.

	pH	Turbidity	TDS	Cl^-	Total Alkalinity	Total Hardness	$SO^{2-}{}_4$	NO_3^-	F^-	Fe	As
pH	1										
Turbidity	0.63										
TDS	-0.23	0.02	1								
Cl^-	0.59	0.93	0.14	1							
Total Alkalinity	-0.63	-0.60	0.53	-0.61	1						
Total Hardness	-0.18	0.15	0.33	-0.02	0.19	1					

SO^{2-}_4	0.67	0.82	0.16	0.93	-0.67	-0.09	1				
NO_3^-	-0.21	0.34	0.61	0.5	0.01	0.42	0.42	1			
F^-	0.6	0.62	-0.36	0.56	-0.65	0.55	0.54	-0.01	1		
Fe	0.21	0.57	-0.17	0.57	-0.58	0.48	0.47	0.22	0.46	1	
As	0.6	0.87	-0.16	-0.64	-0.57	0.87	0.87	0.29	0.58	0.5	1

3.1. Ground Water Quality Parameters

3.1.1. Hydrogen Ion Concentration (pH)

The study pH ranged from 7.32 (the lowest) to 8.25 (the highest) showing the alkalinity of groundwater and falling within the range that is considered acceptable (6. 5–8. 5).

3.1.2. Turbidity

Turbidity is a measure of any liquids relative clarity. When the water sample is illuminated it measures the percentage of light dispersed by the substances in the water. Excessive turbidity in water is unsightly and may pose a health risk. Waterborne diseases may result from the regrowth of waterborne pathogens if the causes of high turbidity are not addressed [39]. According to IS:10500-2012 the acceptable limits for turbidity are 1 to 5 NTU respectively. Turbidity in the current study ranged from 1.2 to 19.04 NTU which exceeds the permissible range.

3.1.3. Total Dissolved Solids (TDS)

TDS varied between 160 and 2240 mg/L in this study (BIS defines safe water as having a TDS of less than 500 mg/L). Leaching of soil urban runoff and point pollution sources that discharge through sewage treatment plants or industries are the main sources of total dissolved solids (TDS) [40].

3.1.4. Chloride (Cl^-)

Within the allowed range (250 mgL-1) the chloride concentration varied from 20 to 1000 mg/L. A high concentration of chloride in groundwater is harmful for human health [41].

3.1.5. Total Alkalinity

In drinking water alkalinity levels up to 200 $mgL^{-1}$are permissible any higher than that and the water becomes bitter [42]. In this investigation alkalinity varied between 100 to 800 mg/L which is within permissible bounds (600 mgL^{-1}).

3.1.6. Total Hardness

The water hardness in this study was between 120 -1200 mg/L which is within the permissible range (600 mgL^{-1}). Elevated levels of hardness in groundwater have been linked to kidney stones and heart problems [43].

3.1.7. Sulphate (SO^{2-}_4)

Sulphate concentration varied from 10 to 500 mg/L in the current work, within the acceptable range of 200 mgL^{-1} [44].

3.1.8. Nitrate (NO_3^-)

As a component of the nitrogen cycle nitrate is an ion that occurs naturally. Nevertheless, nitrate in groundwater poses a concern as it can result in methemoglobinemia in infants younger than six months old [44–46]. High nitrogen concentrations that are higher than the 45 mgL^{-1} allowable range are generally harmful to human health [47]. The current investigation shows that nitrate concentrations are higher than allowed ranging from 2- 200 mg/L. High levels of nitrate in drinking water put expectant mothers and their unborn children at risk for health problems [48].

3.1.9. Fluoride (F^-)

Commonly found in groundwater is fluoride. Volcanic activity and different kinds of rocks are related to natural sources. High fluoride concentrations in groundwater are also caused by industrial (clays used in ceramic industries or burning of coals) and agricultural (use of phosphatic fertilizers) activities [49]. It's one of the most reactive elements and lightest halogens [50]. In high concentrations it is typically detected as a notable ion or as a trace amount [51]. Groundwater contains fluoride primarily because of the reaction between host rocks and minerals that contain fluoride. The acceptable range for fluoride concentration in this study was between 0.2 – 5.0
mg/L^{-1}.

3.1.10. Iron (Fe)

Iron-containing mineral rocks weathering is the most common source of iron in groundwater. Iron is present in aquifers naturally in the Fe^{2+} state but after it dissolves in groundwater its concentration increases. It is soluble in this form and generally poses no health risk however when the Fe^{2+} state oxidizes to the Fe^{3+} state groundwater becomes insoluble due to the contact with atmospheric oxygen [52]. Consequently, the concentrations of iron in groundwater are higher than in surface water. Within the permissible range of 1.0 mgL^{-1} the iron content ranged from 0.05 to 5.0 mg/L^{-1} [45–47].

3.1.11. Arsenic (As)

Within the acceptable range of 0. 01 to 0. 05 mgL^{-1} the arsenic content in the water of the studied area varied between 0.001 to 0.05 mg/L^{-1}. Groundwater containing volcanic rock and sulfide mineral deposits may have noticeably higher concentrations of arsenic. As arsine at low temperatures is formed arsenic also enters the atmosphere naturally through bio-methylation. Arsenic-contaminated water can cause skin lesions diabetes pulmonary illness cardiovascular disease and hard patches on the palms and soles of the feet (hyperkeratosis) after long-term consumption.

3.2. Water Quality Index (WQI)

The WQI was calculated in this study using all thirteen parameters. The World Health Organization the Bureau of Standards of India (BIS) and the Indian Council for Medical Research established drinking water quality standards which were used to calculate the WQI. The weighted arithmetic index method which involves the following sequential steps was used to calculate the WQI for water.

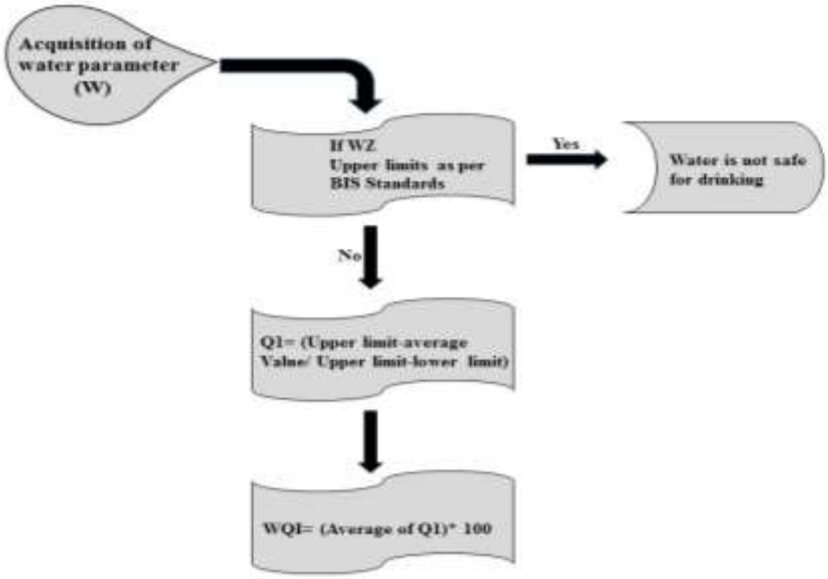

Figure 2. Flow chart to determine the water quality index.

3.2.1. Weightage Factor (Wi)

The parameters' weights (wi) were allocated based on their importance in ensuring water quality. The weightage factor was determined in the following manner.

$$Wi = wi/\Sigma^{n}_{i=1} wi$$

where Wi indicates relative weight, wi indicates the weight of every parameter, and n indicates the number of parameters.

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

The calculation of the sub-index is as follows:

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

where Ve indicates an estimated value for the i^{th} parameter, Vi indicates an ideal value for the i^{th} parameter, Vs indicates a standard permissible value for the i^{th} parameter, and Qi indicates the quality rating for the i^{th} water quality parameter.

3.2.3. Calculation of WQI

To calculate WQI, first there is a calculation of the sub-index for every parameter with the use of the following formula:

$$SIi = wi \times qi$$

where SI_i indicates the sub-index of its parameter, qi indicates the sub-rating based on the concentration of i^{th}, and n represents the numbers of the parameter.

Each value of the sub-index of each groundwater sample was added to calculate the overall WQI.

$$WQI = \Sigma SI_i$$

Calculated values of WQI were classified into five different categories: very good, good, poor, very poor, and unfit for drinking, as depicted in Table 4.

Table 4. Groundwater quality as per WQI range.

WQI	**Category**
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
>100	Unsuitable for drinking

IV. RESULT AND DISCUSSION

4.1. Correlations Matrix and Statistical Assessment

Groundwater quality parameters were assessed for the tabulation of the correlation matrix and general statistical analysis, as given in Tables 2 and 3. A correlation matrix of eleven different parameters was created with the help of MS Excel. Among the eleven parameters, pH positively correlates with turbidity, chloride, sulphate, and calcium. Turbidity is significantly correlated with chloride, fluoride, and arsenic. Chloride has a positive correlation with sulphate, fluoride, and calcium. Sulphate positively correlates with arsenic and calcium, and alkalinity negatively correlates with hardness, fluoride, and arsenic.

Tables 2 and 3 present the parameters of groundwater quality that were evaluated for the purpose of tabulating the correlation matrix and conducting a general statistical analysis. With the aid of Microsoft Excel, a correlation matrix comprising eleven distinct parameters was produced. Among the eleven variables turbidity calcium sulfate and chloride all have positive correlations with pH. There is a strong correlation between turbidity and arsenic fluoride and chloride. There is a positive correlation between calcium fluoride and sulphate and chloride. The elements calcium and sulphate have a positive correlation while the elements hardness fluoride and arsenic have a negative correlation with alkalinity. Arsenic and fluoride have an inverse relationship. There is a positive correlation between the maximum quality parameters. Other heavy metals like Pb, Cd and Cr can become present when Fe and As concentrations are higher. Since these are far more important and crucial heavy metals close observation is needed to ensure the regions groundwater quality in the future. The presence of Fe, (SO^{2-}_4), and (NO_3^-) can lead to the existence of cadmium.

4.2. Spatial Distribution Pattern

Spatial Distribution of Sampling Points Across Rural and Urban Areas The spatial distribution of groundwater sampling points across rural and urban areas in Panchkula district was based on the stratification of the study area into the alluvial aquifer system and the hard rock aquifer system, and the further stratification based on land use patterns. The sampling points were distributed proportionally to the areal extent of each stratum, with a higher number of sampling points in the alluvial aquifer system due to its larger areal extent and greater significance as a source of drinking water.

In the alluvial aquifer system, which covers the southwestern part of the district, a total of 70 sampling points were selected. Of these, 40 sampling points were located in rural areas, primarily in agricultural lands and villages, while 30 sampling points were located in urban areas, including the major towns of Panchkula, Kalka, and Pinjore. The rural sampling points were selected to cover the range of agricultural practices in the district, including irrigated and rainfed agriculture, and to capture the potential impacts of fertilizer and pesticide use on groundwater quality. The urban sampling points were selected to cover the range of urban land uses, including residential areas, commercial areas, and industrial areas, and to capture the potential impacts of urban activities, such as wastewater discharge and solid waste disposal, on groundwater quality.

In the hard rock aquifer system, which covers the northeastern part of the district, a total of 30 sampling points were selected. Of these, 20 sampling points were located in rural areas, primarily in the hilly terrain of the Siwalik Hills, while 10 sampling points were located in urban areas, including the towns of Raipur Rani and Barwala. The rural sampling points were selected to cover the range of land uses in the hilly terrain, including forest areas, grasslands, and agricultural lands, and to capture the potential impacts of land use change and deforestation on groundwater quality. The urban sampling points were selected to cover the range of urban activities in the hilly terrain, including tourism and mining, and to capture the potential impacts of these activities on groundwater quality.

V. CONCLUSIONS

The flat alluvial region of Panchkula has good groundwater quality overall according to the results of the current research conducted. One of the best aquifer systems in terms of hydrogeology is formed by the thick Quaternary sediments which are layered. A good water flow is made possible by this configuration improving the quality of the groundwater. However unsustainable human activities have been observed in various locations and have increased groundwater nitrate concentrations especially in the north-central parts of the study area. These activities include the use of synthetic nitrogen fertilizers combustion engines in vehicles municipal effluent disposal through sludge spreading on fields atmospheric emissions from energy production septic tanks leaking slurry or manure tanks leaking sewage systems accidental spills of nitrogen-rich compounds and nitrogen-rich waste disposal using sound injection techniques. The quality of water resources is significantly impacted in urban areas with high population densities mainly as a result of increased agricultural practices industrialization and human activity. These elements work together to raise the water contents nitrate and magnesium levels. Significant nitrate concentrations are introduced through untreated urban wastewater discharge and agricultural runoff from nitrogen-rich fertilizers. Nitrates are introduced into water bodies by surface runoff which is exacerbated by urbanization and changes in land use which reduce infiltration. along with improper waste disposal practices industrial discharges vehicle emissions and human activity. increases in nitrate pollution. As a result, the high nitrate content of the water highlights the urgent need for all-encompassing pollution control and urban water resource sustainability strategies. The areas lower WQI values indicate that the groundwater is potable and safe guaranteeing safe water quality for domestic use and drinking. The groundwater in the area is safe to drink according to the analysis in this study which is based on WQI.

REFERENCES

[1] Ouyang, T.; Zhu, Z.; Kuang, Y. 2006. Assessing impact of urbanization on river water quality in the Pearl River Delta Economic Zone, China. Environ. Monit. Assess, 120 313–325.

[2] Saha, D.; Sahu, S. 2015. A decade of investigations on groundwater arsenic contamination in Middle Ganga Plain, India. Environ. Geochem. Health. 38(2): 315–337.

[3] Brindha, K.; Elango, L.; RNV, N. 2011. Spatial and temporal variation of uranium in a shallow weathered rock aquifer in southern India. J. Earth Syst. Sci. **2011**, 120(5): 911–920.

[4] Meraj, G. 2021. Assessing the Impacts of Climate Change on Ecosystem Service Provisioning in Kashmir Valley India. Ph.D. Thesis, Suresh Gyan Vihar University, Jaipur, India.

[5] Alban, K. 2014. Simulink application on dynamic modeling of biological waste water treatment for aerator tank case. Int. J. Sci. Technol. Res. 3(11): 69–72.

[6] Alban, K.; Irma, K.; Elisabeta, P. 2016. Simulink programming for dynamic modelling of activated sludge process: Aerator and settler tank case. Fresenius Environ. Bull. 25(8): 2891–2899.

[7] Mangukiya, R.; Bhattacharya, T.; Chakraborty, S. 2012. Quality characterization of groundwater using water quality index in Surat city, Gujarat, India. Int. Res. J. Environ. Sci. 1(4): 14–23.

[8] Kavitha, M.T.; Divahar, R.; Meenambal, T.; Shankar, K.; Vijay Singh, R.; Haile, T.D.; Gadafa, C. 2019. Dataset on the assessment of water quality of surface water in Kalingarayan Canal for heavy metal pollution, Tamil Nadu. Data Brief. 22 878–884.

[9] Kavitha, M.T.; Shankar, K.; Divahar, R.; Meenambal, T.; Saravanan, R. 2019. Impact of industrial wastewater disposal on surface water bodies in Kalingarayan canal, Erode district, Tamil Nadu, India. Arch. Agric. Environ. Sci. 4(4): 379–387.

[10] Sinha, K.K.; Gupta, M.K.; Banerjee, M.K.; Meraj, G.; Singh, S.K.; Kanga, S.; Farooq, M.; Kumar, P.; Sahu, N. 2022. Neural Network-Based Modeling of Water Quality in Jodhpur, India. Hydrology **2022**, 9(5): 92.

[11] Panigrahi, T.; Das, K.K.; Dey, B.S.; Panda, R.B. 2012. Assessment of Water Quality of river Sono, Balasore. Int. J. Environ. Sci. 3(1): 49–56.

[12] Gebrehiwot, A.B.; Tadesse, N.; Jigar, E.2011. Application of water quality index to assess suitability of groundwater quality for drinking purposes in Hantebet watershed, Tigray, Northern Ethiopia. ISABB J. Food Agric. Sci. 1(1): 22–30.

[13] WHO. Guideline for Drinking Water Quality, 4th ed.; World Health Organization: Geneva, Switzerland, 2017.

[14] Diersing, N.; Nancy, F. Water Quality: Frequently Asked Questions; Florida Brooks National Marine Sanctuary: Key West, FL, USA, 2009.

[15] Panneerselvam, B.; Paramasivam, S.K.; Karuppannan, S.; Selvaraj, P. 2020. A GIS-based evaluation of hydro chemical characterization of groundwater in hard rock region, South Tamil Nadu. India Arab. J. Geosci. 13 837.

[16] Smith, D.G. 1990. A better water quality indexing system for rivers and streams. Water Res. 24(10): 1237–1244.

[17] Debnath, J.; Sahariah, D.; Saikia, A.; Meraj, G.; Nath, N.; Lahon, D.; Annayat, W.; Kumar, P.; Chand, K.; Singh, S.K. 2023. Shifting Sands: Assessing Bankline Shift Using an Automated Approach in the Jia Bharali River, India. Land 12(3): 703.

[18] Stambuk Giljanvoic, N. 1999. Water quality evaluation by index in Dalmatia. Water Res. 33(16): 3423–3440.

[19] Pesce,S.F.; Wunderlin, D.A. 2000. Use of water quality indices to verify the impact of Cordoba city (Argentina) on Suquiariver. Water Res. 34(11): 2915–2936.

[20] Sargaonkar, A.; Deshpande, V.2003. Development of an overall index of pollution for surface water based on general classification scheme in Indian context. Environ. Monit. Assess. 89 43–67.

[21] Saeedi, M.; Abessi, O.; Sharifi, F.; Meraji, H. 2010. Development of Ground Water Quality Index. Environ. Monit. Assess. 163 327–335.

[22] Alexakis, D.E. 2020. Meta-Evaluation of Water Quality Indices. Application into Groundwater Resources. Water. 12(7): 1890.

[23] Yisa, J.; Jimoh, T. 2010. Analytical Studies on Water Quality Index of river Landzu. Am. J. Appl. Sci. 7(4): 453–458.

[24] Finotti, A.R.; Finkler, R.; Susin, N.; Schneider, V.E. 2015. Use of water quality index as a tool for Urban Water Resource Management. Int. J. Sustain. Dev. Plann. 10(6): 781–794.

[25] Kannel, P.R.; Lee, S.; Lee, Y.S.; Kanel, S.R.; Khan, S.P. 2007. Application of water quality indices and dissolved oxygen as indicators of river water classification and urban impact assessment. Environ. Monit. Assess. 132 93–110.

[26] Tomar, P.; Singh, S.K.; Kanga, S.; Meraj, G.; Kranjˇci´c, N.; Ðurin, B.; Pattanaik, A. 2021. GIS-Based Urban Flood Risk Assessment and Management—A Case Study of Delhi National Capital Territory (NCT), India. Sustainability 13(22): 12850.

[27] Singh, P.; Nath, S.; Prasad, S.C.; Nema, A.K. 2008. Selection of suitable aggregation function for estimation of aggregate pollution for river Ganges in India. J. Environ. Eng.134(8): 689–701.

[28] Aravindan, S.; Shankar, K.; Ganesh, B.P.; Rajan, K.D. 2010. Hydro-geochemical mapping of in the hard rock area of Gadilam River basin, using GIS technique. Tamil Nadu Indian J. Appl. Geochem. 12 209–216.

[29] Shankar, K.; Aravindan, S.; Rajendran, S. 2010. 2010. GIS based groundwater quality mapping in Paravanar River Sub-Basin, Tamil Nadu, India. Int. J. Geomat. Geosci. 1(3): 282–296.

[30] Venkateswaran, S.; Karuppannan, S.; Shankar, K. 2012. Groundwater quality in Pambar sub basin, Tamil Nadu, India using GIS. Int. J. Recent. Sci. Res. 3(10): 782–787.

[31] Magesh, N.S.; Elango, L. 2019. Spatio-temporal variations of fluoride in the groundwater of Dindigul District, Tamil Nadu, India: A comparative assessment using two interpolation techniques. In GIS and Geostatistical Techniques for Groundwater Science; Elsevier: Amsterdam, The Netherlands, 283–296.

[32] Balamurugan, P.; Kumar, P.S.; Shankar, K.; Nagavinothini, R.; Vijayasurya, K. 2020. Non-carcinogenic risk assessment of groundwater in Southern Part of Salem District in Tamilnadu, India. J. Chil. Chem. Soc. 65(1): 4697–4707.

[33] Kanga, S.; Singh, S.K.; Meraj, G.; Kumar, A.; Parveen, R.; Kranjˇci´c, N.; Ðurin, B. 2022. Assessment of the Impact of Urbanization on Geoenvironmental Settings Using Geospatial Techniques: A Study of Panchkula District, Haryana. Geographies. 2(1): 1–10.

[34] Horton, R.K. 1965. An index number system for rating water quality. J. Water Pollut. Control Fed. 37(3): 303–306.

[35] Choudhury, U.; Singh, S.K.; Kumar, A.; Meraj, G.; Kumar, P.; Kanga, S. 2023. Assessing Land Use/Land Cover Changes and Urban Heat Island Intensification: A Case Study of Kamrup Metropolitan District, Northeast India (2000–2032). Earth. 4(3): 503–521.

[36] Meraj, G.; Kanga, S.; Kranjˇci´c, N.; Ðurin, B.; Singh, S.K. 2021. Role of Natural Capital Economics for Sustainable Management of Earth Resources. Earth. 2(3): 622–634.

[37] Alobaidy, A.M.; Abid, H.S.; Maulood, B.K. 2010. Application of water quality index for assessment of Dokan lake ecosystem, Kurdistan region, Iraqi. J. Water Res. Prot. 2(9): 792–798.

[38] Shankar, K.; Kawo, N.S. 2019. Groundwater quality assessment using geospatial techniques and WQI in North East of Adama Town, Oromia Region. Ethiopia Hydrospatial Anal. 3(1): 22–36.

[39] Sud, A.; Kanga, R.; Singh, S.K.; Meraj, G.; Kanga, S.; Kumar, P.; Ramanathan, A.; Sudhanshu; Bhardwaj, V. 2023. Simulating Groundwater Potential Zones in Mountainous Indian Himalayas—A Case Study of Himachal Pradesh. Hydrology 10(3): 65.

[40] Egereonu, U.U.; Nwachukwu, U.L. 2005. Evaluation of the surface and groundwater resources of Efuru River Catchment, Mbano, South Eastern. Nigeria J. Assoc. Adv. Model. Simulat. Tech. Enterpr. 66 53–71.

[41] Majumdar, D.; Gupta, N. 2000. Nitrate pollution of groundwater and associated human health disorders. Indian. J. Environ. Health. 42 28–39.

[42] Haddad, B.O.; Delpasand, M.; Loáiciga, A.H. 2021. Economic, Political and Social Issues in Water Resources; Elsevier: Amsterdam, The Netherlands. 217–257.

[43] Anderson, T.W.; Neri, L.C.; Schreiber, G.B.; Talbot, F.D.; Zdrojewski, A. 1975. Letter: Ischemic heart disease, water hardness and myocardial magnesium. Can. Med. Assoc. J. 113(3): 199–203.

[44] IS 10500; 2015. Drinking Water Specification (Second Revision). BIS (Bureau of Indian Standard): New Delhi, India. 2–6.

[45] WHO. International Standards for Drinking Water; World Health Organization: Geneva, Switzerland, 1992.

[46] ICMR. Manual of Standards of Quality for Drinking Water Supplies; ICMR: New Delhi, India, 1975.

[47] Ramakrishnaiah, C.R.; Sadashivaiah, C.; Ranganna, C. 2009. Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State India. J. Chem. 6 523–530.

[48] Pandey, H.K.; Tiwari, V.; Srivastava, S.K. 2020. Groundwater quality assessment of Allahabad smart city using GIS and water quality index. Sustain. Water Resour. Manag. 6(2): 28.

[49] Burnt, R.; Vasak, L.; Griffieon, J. 2004. Fluoride in Groundwater: Probability of Occurrence of Excessive Concentration on Global Scale; Report nr. SP 2004-2; IGRAC: Delft, The Netherlands, 2004.

[50] Ram, A.; Tiwari, S.K.; Pandey, H.K.; Singh, Y.V. 2021. Groundwater Quality Assessment Using Water Quality Index (WQI) under GIS Framework. Appl. Water Sci. 11(46): 46.

[51] Nath, N.; Sahariah, D.; Meraj, G.; Debnath, J.; Kumar, P.; Lahon, D.; Chand, K.; Farooq, M.; Chandan, P.; Singh, S.K.; 2023. Land Use and Land Cover Change Monitoring and Prediction of a UNESCO World Heritage Site: Kaziranga Eco-Sensitive Zone Using Cellular Automata-Markov Model. Land 12(1): 151.

[52] Ding, X.; Song, L.; Xu, Z. 2019. Effects of Fe^{3+} on Acute Toxicity and Regeneration of Planarian (Dugesia japonica) at Different Temperatures. Hindawi Bio Med Res. Int. 2019 8591631.