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Assessment of Urban Growth and its impact on Groundwater Quality using Remote Sensing and GIS techniques in GMDA Area, Assam, India

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Abstract - Land use/ Land cover (LU/ LC) monitoring is essential for water conservation and management. In the GMDA area, uncontrolled urban growth has led to the deterioration of groundwater quality, with around 70% of the population relying on groundwater for drinking and other household purposes. An attempt has been made in this study to comprehend the influence of LU/LC on groundwater quality in the Guwahati Metropolitan Authority (GMDA) area. Landsat 5 TM and OLI satellite data for 2000 and 2019 were used to prepare LU/ LC maps using different interpretation elements like tone, size, texture, pattern and association. Using supervised classification, LU/ LC classes identified were recognised such as vegetation, built-up areas, water bodies, sandbar and fallow land. The groundwater quality data collected from Central Ground Water Board (CGWB) were used to analyse the distribution of groundwater quality parameters like pH, Ca, $CaCO_3$, F, Cl, HCO_3, K, SO_4, Mg, Na, NO_3 and TDS using Inverse Distance Weightage (IDW). Comparing the LU/LC of the years 2000 and 2020, a significant change was observed in the built-up areas, and vegetation by around 32% and 13% whereas, a decrease in areas with waterbody and fallow land by 11.5% and 45% was calculated. Additionally, a change in the increase in the concentration of some of the parameters like F, K, Mg and SO_4 from 2014 to 2019 was also recorded.

Index Terms - Groundwater quality, urban growth, remote sensing, GIS

INTRODUCTION

Urbanisation has sustainable consequences for changes in demographic features and physical landscape. Unplanned and rapid urbanisation can have a negative impact on different environmental components particularly, land and water. Water is a significant resource and a fundamental necessity for the sustenance of the life of flora and fauna. According to UNEP, 2001, the issue is aggravated in India as 16% of the world's human population is occupying only 2.5 % of the total geographical territory. Therefore, to cope with environmental changes and facilitate sustainability, a thorough understanding of the processes of urbanization-induced land-cover change is required (Patra et al., 2018; Jhariya & Khan, 2018). Approximately 1.5 billion people rely on groundwater resources withdrawing 20% of global water withdrawals. Topography, lithology, geological structures, depth of weathering, the extent of fractures, secondary porosity, slope, drainage pattern, landforms, land use/land cover, elevation, rainfall, and other climatic conditions, as well as the interrelationship between these factors, govern the occurrence and movement of groundwater in an area. Unplanned urbanisation and rising human demand on the hydrogeomorphologic system frequently lead to changes in the groundwater recharge mechanism (Prabir et al, 2012).

Anthropogenic activities are the primary cause of changes in land use and land cover (LULC). Many studies have been conducted to investigate land use/ land cover (LU/LC) change and its effects on groundwater quality and quantity utilising remote sensing (RS) and geographic information systems (GIS) (Prabir et al, 2012). Elmahdy et al., 2020 and Singh et al., 2010 emphasised the impact of change in LU/LC on groundwater quantity and quality. Various studies integrated the impact of LU/LC changes on groundwater quality (Singh et al, 2011; Venkateswarlu et al., 2014; Khan & Jhariya, 2018, Karimian et al., 2019).

RS/GIS are a useful tool for studying LU/LC changes because of its spatio-temporal coverage capabilities. The rationale of the study lies in understanding the spatio-temporal land use and land cover dynamics and their impact on groundwater quality in the area. Changes in land-use patterns and subsequent inability to enforce land-use regulations have resulted in arbitrary housing building in GMDA, which has increased surface run-off and reduced groundwater recharge. Another issue of groundwater quality degradation due to anthropogenic activities that have been observed is leachate from improperly disposed of solid waste, which causes higher contamination of shallow aquifers, and as a result, extraction pressure is increasing in deeper aquifers for relatively better water quality, illustrating the exploitative perspective toward the most widely used water resource once again (Hazarika et al., 2016).

STUDY AREA

Guwahati Metropolitan Development area (GMDA) is the gateway of North-East India. It is bounded by 26°5'39" N to 26°12'39'' N latitudes and 91°34'39'' E to 91°51'39'' E longitudes. Situated on the southern bank of the river Brahmaputra, the southern and the eastern sides of the region are bounded by hills that are extensions of the Khasi Hills of Meghalaya. The location map is illustrated in Fig. 1.

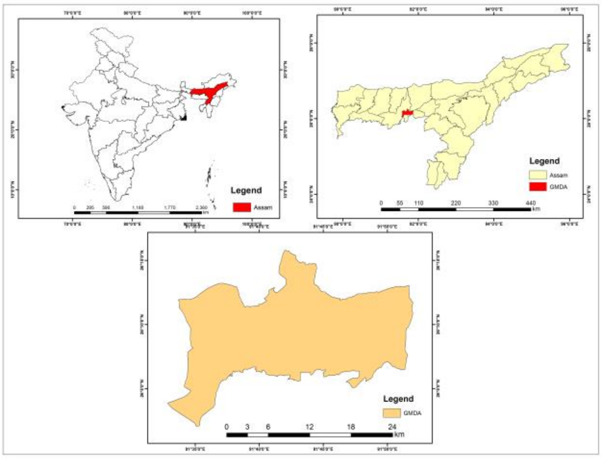

Fig. 1: Location map showing GMDA boundary
Source: Census of India & Guwahati Metropolitan Development Authority

Geologically, Guwahati rests upon the typical Precambrian rock units which are overlain by young and recent alluvium. The region is located at an elevation of about 54 meters above mean sea level. Major streams and rivers of the region originate from the southern and northeastern highlands and flow through natural slope gradients. These include Amchang, Bahini, Basistha Bahini, Bharalu, Khanajan and Mora Bharalu. The river Bharalu dissects the region for a length of about 9 km. Wetlands are located in parts of the central, southeastern and western regions of the city. These are primarily depressed valley areas with remnants of palaeo-channels of Brahmaputra.

Guwahati is underlain by the geological formation of the Achaean / Pre-Cambrian age followed by Quaternary formation. The Achaean and Pre-Cambrians are represented by inselbergs, denudational hills, compound gneissic rocks, granite, schists, amphibolites, pegmatites and basic/acidic intrusions. The Quaternary formation is represented by loose sands of various grades, pebbles, cobbles, gravels, clay and silts. In these rock groups, groundwater is stored in various conditions. In the loose Quaternary foothills, it is stored in porous sand fractures and in the case of hard consolidated foothills, it is stored in the fraction fissures, joints and structurally weak formations. The geological map has been shown in Fig. 2.

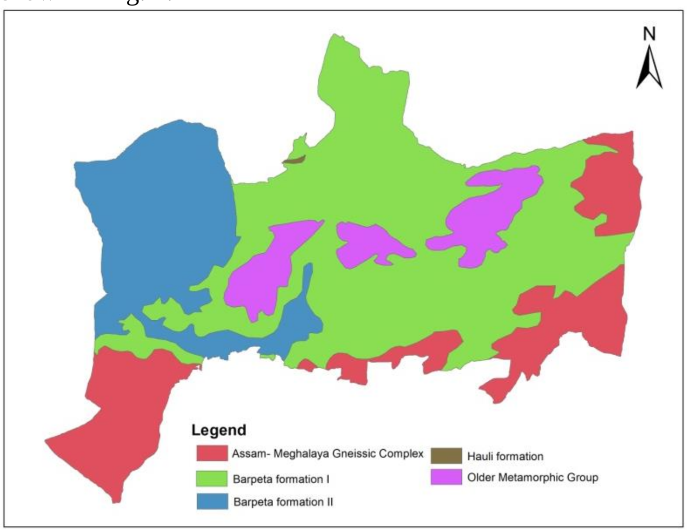

Fig. 2: Geological map of GMDA
Source: Geological Survey of India

Hydrogeological studies revealed the presence of groundwater just under water table conditions in the case of shallow aquifers; however, in the case of deeper aquifers, it is available within the semi-confined to confined conditions. In the loose unconsolidated formations depth to water in the open dug wells ranges from 2 to 4 meters below ground level during the pre-monsoon period. Dug wells located in the foothills zone however show deeper groundwater levels ranging between 5 to 10 meters below ground level during the pre-monsoon period. Shallow tube wells are constructed in the loose formation down to 30 m. The natural drainage system of the city is not uniform and is very much influenced by the landscape pattern of the city.

METHODOLOGY

To assess the LU/LC change and its impact on groundwater quality, Landsat TM and OLI satellite imageries have been used from the USGS website (www.earthexplorer.com) for the years 2000 and 2020. A geological map has been prepared using Geological Survey of India (GSI) data. The data were geo-rectified into World Geodetic System 1984 and datum 46 North. Groundwater quality data for the period of 2014-2019 have been obtained from Central Ground Water Board (CGWB) website. The preparations of groundwater quality maps were prepared using the Inverse Distance Weightage (IDW) raster interpolation technique of various groundwater quality parameters. The groundwater sampling locations were imported into ArcGIS and used to prepare maps for selected parameters namely, pH, Ca, $CaCO_3$, Cl, HCO_3, F, K, SO_4, Mg, NO_3 and TDS.

RESULTS AND DISCUSSION

Spatial distribution map

Groundwater quality maps are useful in determining the suitability of water for various reasons, primarily drinking. Selected parameters namely, pH, Ca, $CaCO_3$, Cl, HCO_3, F, K, SO_4, Mg, NO_3 and TDS for the years 2014 and 2019 have been presented in figures 3, 4 and 5 and change in the occurrence has been shown in Table 1.

pH: pH is one of the most significant water quality parameters with the optimum which ranges from 6.5-8.5. It is a measure of hydrogen ion concentration in the water. The pH values indicate the acidic, basic and alkaline nature of water (Singha et al., 2015, Khan and Jhariya, 2018). According to the data, pH in the study area ranges from 7.38 mg/L to 8.78 mg/L, which is within acceptable limits. Spatial distribution for the mentioned parameter has been depicted in Fig. 1(a). It can be observed that there has been an increase in the pH level spatially in 2019 in the range of 8.41 to 8.78 mg/L as shown in Table 1 and Fig. 3(a).

TDS: The concentration of mineral compositions dissolved in water are known as total dissolved solids (TDS). Desirable limit within the permissible limit ranges from 500-2000 mg/L. Fig. 1(b) shows the spatial distribution of TDS in the study area which range from 114.46 to 339.47 mg/L. Table 1 and Fig. 3(b) shows a maximum increase in the variation of TDS in the range 204.47 - 249.47 mg/L in the period.

Chloride (Cl-): Water contains various amounts of chloride, depending on the geochemical circumstances. Industrial waste, sewage disposal, and the leaching of saline residues into the soil can all cause chloride concentrations. Drinking water with a high chloride percentage has a salty taste to it. The permissible limit for chloride concentration ranges between 1000 mg/L. It can be observed that there has been an increase in the chloride concentration spatially in 2019 in the range 24.81 – 48 mg/L as shown in Table 1 and Fig. 3(c). Overall, the water samples are within the permissible limit in both years.

Total Hardness (as $CaCO_3$): Hardness is caused due to the presence of carbonates and bicarbonates of calcium and magnesium, chlorides, nitrates and sulphates of calcium and magnesium. The permissible limit of $CaCO_3$ is 200 mg/L. The total hardness of the water samples in the study area varies from 69-267 mg/L in the time period. There has been a maximum increase in the area under the range 108 – 148 mg/L since 2014 as shown in Fig. 3(d) and Table 1.

Alkalinity (HCO3-): It is the main alkaline factor in almost all water. Generally, for most water systems, carbonates (CO3 2-) are the least predominant ions whereas bicarbonates (HCO3-) are the dominant anions. The permissible limit of alkalinity is 200 mg/L. Table 1 and Fig. 4(a) shows the spatial distribution of alkalinity in the study area. It has been observed there is a maximum increase in the variation of alkalinity in the range 81- 111 mg/L in the period.

Fluoride (F): It is a natural pollutant of water commonly found in the form of fluorine. Groundwater usually contains fluoride dissolved by geological formations. The permissible limit for fluoride is 1.5 mg/L. Excessive fluoride concentration can cause skeletal fluorosis or fluorosis. The concentration of F in the water samples in the study area varies from 0.2 to 6.2 mg/L in the time period. There has been a maximum increase in the area under the range of more than 1.5 mg/ L spatially since 2014 which are beyond the permissible limit as shown in Fig. 4(b) and Table 1.

Potassium (K+): The majority of species require potassium in their diet. Potassium also plays an important part in plant growth. Excess potassium, on the other hand, is dangerous in water because it spreads quickly due to its great mobility. Table 1 and Fig. 4(c) show the spatial distribution of potassium concentration in the study area. Overall the water samples are within the permissible limit in both years.

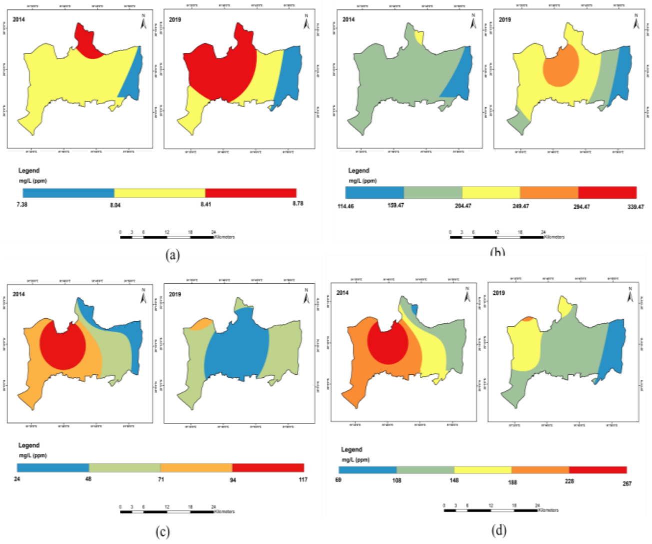

Fig. 3: Spatial distribution for the year 2014 and 2019: (a)pH (b)TDS (c)Cl (d)$CaCO_3$
Source: Central Ground Water Board

Magnesium (Mg2+): Magnesium is prevalent in groundwater. Magnesium ion is required for cell activity during enzyme activation. However, water has an unpleasant taste when the concentration exceeds the allowed limits. The permissible limit of the concentration of Mg is 100 mg/L. Table 1 and Fig. 4(d) show the spatial distribution of the concentration of magnesium in the study area. Overall, the water samples are within the permissible limit in both years.

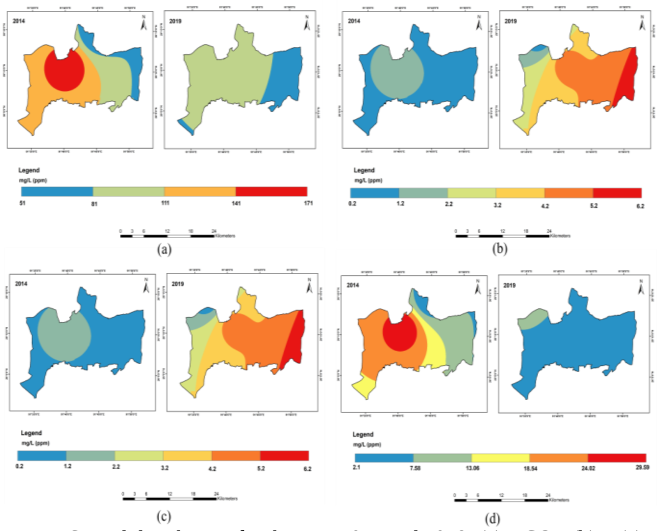

Fig. 4: Spatial distribution for the year 2014 and 2019: (a) HCO_3- (b) F (c)K+ (d) Mg2+
Source: Central Ground Water Board

Calcium (Ca++): Calcium is formed in water mostly as a result of the presence of minerals such as limestone, dolomite, gypsum, and gypsiferous. The BIS specifies a calcium acceptable limit of 75-200 mg/l. The spatial distribution of the concentration of calcium in the study area for the time period has been shown in Table 1 and Fig. 5(a). Overall, the water samples are within the permissible limit in both years.

Sodium (Na+): Sodium is abundant in most natural streams. The highest sodium allowable value is 200 mg/L. High sodium intake can cause increased blood pressure, arteriosclerosis, oedema, and hyperosmolarity. Groundwater with a high concentration of sodium is unsuitable for agricultural usage because it degrades the soil. The concentration of sodium in the study area ranges between 11.73-83.38 mg/L as shown in Fig 5(b) and Table 1 are within the permissible limit in both years.

Nitrate (NO_3): Atmosphere legumes, plant debris, and animal excreta are the main sources of nitrate in water. Nitrate levels in water over 100 mg/l are harsh to the taste and cause physiological irritation in humans. In humans, water from shallow wells containing more than 45 mg/L produces methemoglobinemia, often known as a blue baby syndrome. Higher nitrate concentrations are found mainly due to the application of fertilizers, septic tanks, open dumpsites, inadequate manure management, etc. Nitrate concentration in the study area as shown in Fig. 5(c) is within the permissible limit in both years but Table 1 shows there is an increase in the concentration in 2019.

Sulphate (SO_4--): Sulphur in groundwater is usually in the form of sulphate. The weathering of sulphide-bearing rocks like granite, fertiliser, and rainfall can all cause sulphate to infiltrate groundwater. The permissible limit of concentration of sulphate is 200 mg/L. The spatial distribution of the concentration of sulphate in the study area for the time period has been shown in Table 1 and Fig. 5(d). Overall, the water samples are within the permissible limit in both years.

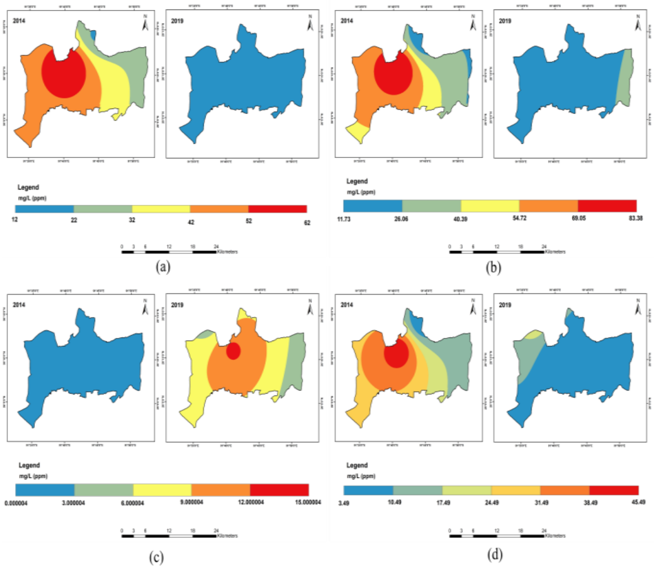

Fig. 5: Spatial distribution for years 2014 and 2019 for (a) Ca (b)Na (c)NO_3 (d) SO_4.
Source: Central Ground Water Board

Parameters	Range	2000(Area in km^2)	2020(Area in km^2)	Change (Area in km^2)
Ca	12-22	1.9188	0	-1.918
	22-32	73.9719	382.548	308.576
	32-42	77.8617	0	-77.861
	42-52	152.141	0	-152.141
	52-62	76.6548	0	-76.654
$Caco_3$	69 - 108	2.8035	60.1371	57.333
	108 - 148	81.7209	230.363	148.642
	148 - 188	71.1495	89.8902	18.740
	188 - 228	151.643	2.1573	-149.486
	228 - 267	75.231	0	-75.231
Cl	24.81 - 48	53.7831	183.1	129.316
	48 - 71	92.6424	190.168	97.525
	71- 94	140.65	9.279	-131.371
	94 - 117	95.472	0.0009	-95.471
Fluoride	0.23 - 1.2	260.736	3.7845	-256.952
	1.2 - 2.2	121.811	18.9981	-102.813
	2.2 - 3.2	0	56.0574	56.057
	3.2 - 4.2	0	99.8739	99.873
	4.2 - 5.2	0	163.056	163.056
	5.2 - 6.2	0	40.7781	40.778
HCO_3	51.21 - 81	5.05512	99.5382	94.483
	81 - 111	9.88281	283.009	273.126
	111- 141	16.09829	0	-16.098
	141- 171	7.21854	0	-7.218
K	2.13 - 7.58	17.2314	361.151	343.919
	7.58 - 13.06	106.759	21.3966	-85.362
	13.06 - 18.54	63.4869	0	-63.486
	18.54 - 24.02	142.04	0	-142.04
	24.02 - 29.5	53.0307	0	-53.030
Mg	7.81 - 13.12	10.1421	280.355	270.212
	13.12 - 18.43	95.2065	93.2067	-1.999
	18.43 - 23.74	48.1509	8.9847	-39.166
	23.74 - 29.05	93.9114	0	-93.911
	29.05 - 34.36	105.429	0	-105.42
	34.36 - 39.67	29.7081	0	-29.708
NO_3	0.000004016 - 3	0		0
	3 - 6	382.5479	56.5227	-326.025

	6 - 9	0	162.229	162.229
	9 - 12	0	153.338	153.338
	12 - 15	0	10.458	10.458
pH	7.67 - 8.04	34.5213	62.2287	27.707
	8.04 - 8.41	316.922	125.177	-191.745
	8.41- 8.78	31.1049	195.1419	164.037
SO_4	3.49 - 10.49	9.9036	332.433	322.529
	10.49 - 17.49	93.6567	44.9631	-48.693
	17.49 - 24.49	49.8879	5.1516	-44.736
	24.49 - 31.49	96.1344	0	-96.134
	31.49 - 38.49	105.121	0	-105.121
	38.49 - 45.49	27.8442	0	-27.844
TDS	114.46 - 159.47	47.511	43.0812	-4.429
	159.47 - 204.47	329.861	70.6158	-259.245
	204.47 - 249.47	5.1759	206.447	201.271
	249.47 - 294.47	0	62.4033	62.403
	294.47 - 339.47	0	0	0
Na	11.72 - 26.06	19.2519	330.024	310.772
	26.06 - 40.39	102.151	52.524	-49.627
	40.39 - 54.72	58.7736	0	-58.773
	54.72 - 69.05	136.605	0	-136.605
	69.05 - 83.38	65.7666	0	-65.766

Table 1: Change in the groundwater quality from 2014 to 2019.
Source: Central Ground Water Board, Guwahati

EVALUATION OF LU/LC MAP

LU/LC map was prepared using supervised classification using Landsat datasets. From 2000 to 2020, there were significant changes in LULC, according to the current study (Table 2 and Fig. 6). Fig. 6 shows the land use/land cover map from 1999 to 2016, as well as the change analysis rate from Table 2. According to this study, the highest LULC changes were reported in the built-up areas, vegetation, by around 32% and 13% while there has been a decrease in areas with waterbody and fallow land by 11.5% and 45% in the time period.

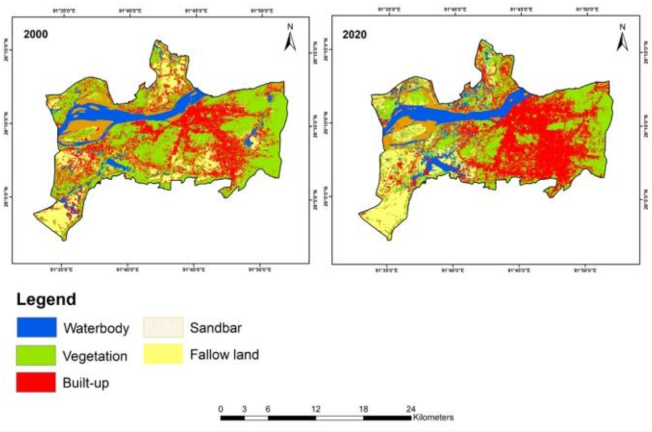

Fig. 6: LU/LC analysis for years 2000 and 2020,
Source: Landsat TM and OLI

LU/LC	2000	2020	Change (%)
Waterbody	33.1119	29.286	-11.55
Veg	518.411	586.225	13.08
BU	183.371	242.243	32.10
Sandbar	4.959	30.3336	511.68
Fallow land	329.971	181.736	-44.92

Table 2: LU/LC changes during 2000 to 2020.
Source: Landsat TM and OLI

CONCLUSION

Because land use and land cover change have a big impact on groundwater quality, it's important to assess it to make sure it's safe to drink. Landsat satellite imageries were used to measure LULC for the years 2000 and 2020. In this study, it is found that there is a drastic change in the settlement area.

LULC analyses reported changes in the built-up areas, vegetation, by around 32% and 13% during the time period. On the other hand, there is a decrease in areas with waterbody and fallow land by 11.5% and 45% between 2000 and 2020. The association between LULC change and groundwater quality has been subjectively established, and it has been discovered that fluoride contamination is primarily concentrated in the GMDA settlement areas. Fluoride concentrations in groundwater increased in 2019, especially in the settlement area, showing that anthropogenic activities in the study region caused the groundwater to surpass the BIS permissible limit.

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