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Assessment of Groundwater Quality in Hyderabad City - A Physicochemical Perspective

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Abstract
The influence of urbanization on groundwater quality is a significant concern globally. As urban areas continue to expand and populations grow, various factors associated with urbanization can affect groundwater quality. This could include pollutants leaking through pavements and roadways, inappropriate waste dumping, spills from below ground storage tanks, industrial activity and agricultural runoff from suburban areas. These contaminants can seep into the groundwater, degrading its quality. Additionally, the over-extraction of groundwater to meet the demands of urban populations can lead to the depletion of aquifers and a reduction in water quality. Urban groundwater quality will vary depending on local conditions and management approaches worldwide. The current study examines the groundwater quality in Hyderabad City by analyzing the Water Quality Index (WQI) in pre and post-monsoon seasons over a period of three years, from 2018 to 2020. The significant physicochemical parameters such as Hydrogen Ion Concentration (P^H), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Bicarbonate (HCO_3^-) and Carbonate (CO_3^{2-}), Fluoride (F^-), Chloride (Cl^-), Nitrate (NO_3^-), Sulphate (SO_4^{2-}), Potassium (K^+), Sodium (Na^+) , Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Total Hardness (TH), of groundwater quality are considered to analyze the Water Quality Index for selected bore well locations in Hyderabad City. The groundwater quality index is essential for understanding the relationships among measured points and assessing the overall contamination of groundwater. Assessment of groundwater quality can provide valuable information to stakeholders, including government agencies, water resource managers, and researchers, to understand the varying dynamics in groundwater quality and take appropriate measures to ensure sustainable water management practices in Hyderabad City.
Keywords: Groundwater, Quality, Urban Areas, Water Quality Index (WQI).

Introduction

Groundwater is becoming an increasingly demanding concern for urban and rural areas globally due to water scarcity driven by climate change and global warming over the past few decades. Nickson et al. (2005) estimate that the global population is relying upon groundwater for consumption purposes about one-third of its availability. Additionally, the World Bank's 1998 report states that groundwater meets rural domestic requirements by about 85% and urban water needs by about 50%. Research literature has demonstrated that seasonal variations in groundwater quality are closely linked to land use practices and potential contaminant sources. Urban areas with higher human activities and industrial zones may show variations in groundwater quality due to seasonal changes in pollutant inputs. While local studies conducted in specific urban areas have provided valuable insights into the spatiotemporal variations of groundwater quality. These studies often focus on the impacts of urbanization, industrial activities, and population density on seasonal groundwater quality fluctuations. Seasonal variations in groundwater levels can influence the movement and mixing of contaminants within aquifers. Changes in water table elevations can cause shifts in hydraulic gradients, altering the direction and rate of contaminant transport. Understanding these processes is crucial for assessing the impact of pollutants and identifying potential sources of contamination. While the availability of groundwater is vital, its quality is an equally significant aspect. During the wet season, precipitation increases, leading to recharge of aquifers. Conversely, the dry season experiences limited rainfall and increased extraction of groundwater. These variations can affect the groundwater quality in several ways. According to World Health Organization (WHO) in 2011, human diseases of nearly 80% are attributed to poor water quality. This statistic underscores how crucial it is to protect the public's health by ensuring that everyone has access to clean, safe drinking water. Contaminated groundwater can pose serious health risks for individuals who depend on it for drinking, cooking, and other domestic purposes. Assessing groundwater quality helps identify specific contaminants and their concentrations, enabling appropriate treatment methods to be implemented to ensure the water's safety. Monitoring and evaluating the quality of groundwater in Hyderabad city is critical owing to variations influenced by geological formations, land use practices, and potential sources of contamination. Regular evaluations are crucial to maintain water suitability for various purposes. The primary goal of this study is to inspect the groundwater quality condition by means of the water quality index (WQI) which offers a thorough groundwater quality assessment by considering multiple physicochemical parameters. The benefit of the WQI is that it combines multiple parameters into a single index, making it easier to evaluate the overall groundwater quality and contamination level within the study area. It also facilitates the comparison of different groundwater sources and can help in decision-making processes regarding water management and treatment strategies.

Study Area

Hyderabad, the capital city of the Indian state of Telangana, is under the jurisdiction of the Greater Hyderabad Municipal Corporation (GHMC). Situated on the Deccan Plateau at an average altitude of 536 meters MSL, latitude and longitude of Hyderabad is 17.366° N and 78.476° E respectively. Positioned centrally within Telangana Province, Hyderabad lies along the Musi River and showcases unique geological features typical of the Deccan Plateau's prominent upland sections. The weathered and fractured basaltic rocks of the Deccan Traps form significant aquifers in Hyderabad. These aquifers are commonly unconfined or shallow in nature. The weathered zone of the basalt acts as a storage unit for groundwater. It has high permeability because of fractures and joints, permitting water to pass into the rock and recharge the aquifer. In addition to the basaltic aquifers, Hyderabad also possesses sedimentary rock formations that host confined or deeper aquifers. These sedimentary aquifers consist of sand stones, shales and other sedimentary deposits. The confined aquifers are relatively less accessible and may require drilling deeper wells for groundwater extraction. Hyderabad heavily relies on groundwater to meet its water demands. The shallow basaltic aquifers are particularly important for the city's water supply. The weathered basaltic layer acts as a primary storage reservoir, storing rainwater and allowing for its extraction through wells and bore holes. Hyderabad has a distinct climate borders on a hot semi-arid environment, exhibiting characteristics of both tropical and arid climatic conditions. Hyderabad gets 810.5 mm of rain on average per year and average yearly temperature is 26.7 °C. According to the estimates provided by the UN World Population Prospects, the population of Hyderabad in 2021 is projected to be approximately 10.2 million people, which is equivalent to 1.02 Crore. The extent of built-up areas in Hyderabad has been expanding due to rapid urbanization and population growth. Built-up areas, with their dense concentration of structures and impervious surfaces, limit natural rainwater infiltration and reduce the potential for groundwater recharge. The following Fig. 1 shows the Base map of the Hyderabad.

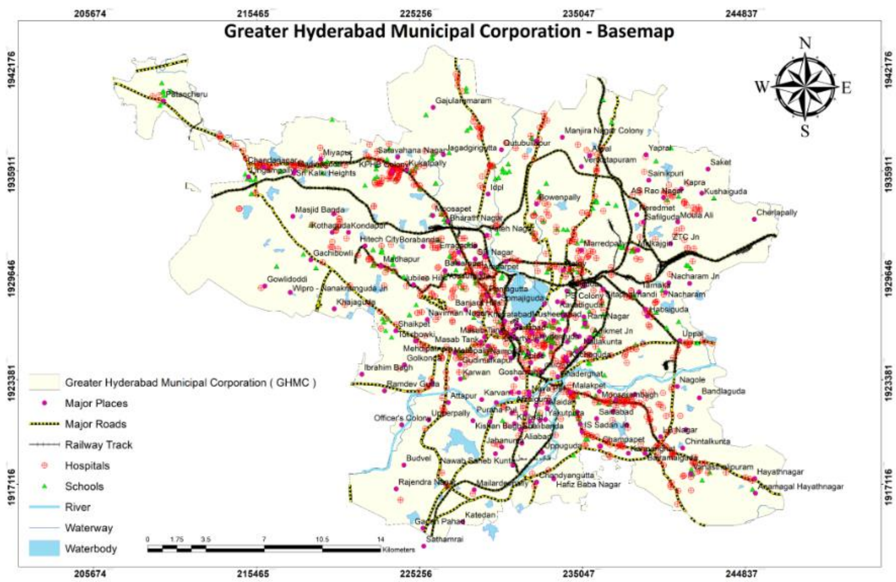

Fig. 1. Base map of Hyderabad City

Data and Methodology

Data on groundwater quality of physiochemical parameters for pre and post-monsoon seasons of 2018, 2019, and 2020, respectively, are retrieved from the Telangana open data portal provided by the Telangana groundwater department to conduct groundwater quality analysis. Table 1 displays the groundwater quality data locations.

Table 1. Location of Groundwater quality Data

Location No	**Mandal**	**Location Name**	**Lat**	**Long**
1	Ameerpet	S.R.Nagar	17.44233	78.44392
2	Asifnagar	Himayanagar	17.39764	78.44525
3	Asifnagar	Kulsanapur	17.374	78.437
4	Bandlaguda	Chandraingutta	17.333	78.484
5	Charminar	DarulShifa	17.381	78.485

6	Maredpally	Maredpally (s)	17.441	78.509
7	Nampally	Nampally	17.385	78.474
8	Saidabad	Juvinile home	17.361	78.508
9	Alwal	Old Alwal	17.494	78.508
10	Balanagar	Balanagar	17.47	78.45
11	Kukatpally	Kaithalapur	17.47	78.4
12	Kukatpally	Kukatpally	17.481	78.397
13	Malkajgiri	Malkajgiri	17.449	78.535
14	Qutubullapur	Gajularamaram	17.53	78.42
15	Qutubullapur	Qutubullapur	17.5	78.46
16	Qutubullapur	Shapurnagar	17.54	78.44
17	Serilingampally	Gachibowli	17.43	78.368
18	Rajender Nagar	Rajender Nagar	17.316	78.405
19	Patancheru	Patancheruvu	17.52583	78.27017
20	R.C.Puram	R.C.Puram	17.5091	78.3003

Estimation of Water Quality Index (WQI)

The Water Quality Index (WQI) technique is commonly used to estimate water quality. This method combines multiple water quality parameters, assigning weights to each parameter according to their relative significance. Water quality data can be summed up into a single number using WQI. The resulting index provides a score that represents the overall water quality. The WQI reflects the cumulative effect of various parameters of water quality on the total water quality. In this study the primary physicochemical variables related to groundwater quality including, Hydrogen Ion Concentration (P^H), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Bicarbonate (HCO_3^-), and Carbonate (CO_3^{2-}), Chloride (Cl^-), Nitrate (NO_3^-), Fluoride (F^-), Sulphate (SO_4^{2-}), Potassium (K^+), Sodium (Na^+) , Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Total Hardness (TH) have been used to assess Water Quality Index for selected bore well locations in Hyderabad City.

Horton's approach was used in this work to estimate WQI, and the following equation (1) was used for calculation:

$$WQI = \frac{\Sigma\, qnWn}{\Sigma\, Wn} \quad (1)$$

Where

qn is n[th] water quality parameter quality rating

Wn is n[th] water quality parameter unit weight

Quality rating (qn)

The Quality rating (qn) is calculated using the equation (2):

$$qn = \frac{(Vn - Vio)}{(Sn - Vio)} * 100 \quad (2)$$

Where

V_{io} is the ideal value, with the exception of pH=7.0 and DO=14.6 mg/L, all ideal values (V_{io}) for drinking water are assumed to be zero.
Sn is the acceptable limit as per BIS (10500: 2012) Standards
Vn is the estimated parameter value of the sample

Unit Weight (Wn)

The primary step is to assign the chosen water parameters a weight in the range of 1 to 5 according to their relative importance to total quality making the water fit for human consumption.

Next, the equation (3) is used to determine the unit weight (Wn) of each quality parameter

$$Wn = \frac{wi}{\Sigma wi} \quad (3)$$

Here wi is the assigned weight of the i[th] parameter and Wn is water quality parameter unit weight
By following these steps, the Water Quality Index allows overall assessment of the groundwater quality at selected locations.
The physicochemical parameters that have been considered in this study are shown in Table 2 below, along with their respective weight and unit weight.

Table 2. Assigned Weight and Unit Weight of Physicochemical Parameters (Whereas EC is measured in µS/cm, pH has no units. All other parameter values are in mg/L)

S.No	Physicochemical Parameter	BIS Standards (IS 10500: 2012) Acceptable Limit	Weight (wi)	Unit Weight Wn = wi / Σwi
1.	P^H	8.5	5	0.10
2.	EC	700	4	0.08
3.	TDS	500	4	0.08
4.	CO_3^{2-}	100 (WHO)	2	0.04
5.	HCO_3^-	200	3	0.06
6.	Cl^-	250	3	0.06

7.	F^-	1	5	0.1
8.	NO_3^-	45	5	0.1
9.	SO_4^{2-}	200	4	0.08
10	Na^+	200 (WHO)	3	0.06
11	K^+	12 (WHO)	2	0.04
12	Ca^{2+}	75	3	0.06
13	Mg^{2+}	30	2	0.04
14	TH	200	5	0.1 (0.06)
			Σwi =50	ΣWn = 1

Result and Discussion

In the present study, the physicochemical parameters are statistically analyzed at 20 selected locations in Hyderabad City. The statistical summary of groundwater seasonal physicochemical parameter composition in the years 2018, 2019 and 2020 is presented in the following Tables. 4, 5 and 6.

Table. 4 Statistical Summary of groundwater seasonal physicochemical parameters composition in 2018

Water quality parameter	**Pre-monsoon - 2018**					**Post-monsoon- 2018**				
	Min	**Max**	**Mean**	**SD**	**CV**	**Min**	**Max**	**Mean**	**SD**	**CV**
P^H	6.84	8.65	7.81	0.47	5.99	6.96	8.50	7.55	0.47	6.17
EC	404.00	2990.00	1220.00	635.12	52.06	412.00	4860.00	1286.53	968.74	75.30
TDS	258.56	1913.60	780.80	406.47	52.06	263.68	3110.40	823.38	619.99	75.30
CO_3^{2-}	0.00	60.00	9.09	17.50	192.52	0.00	60.00	5.26	16.11	306.16
HCO_3^-	103.32	510.87	257.01	104.37	40.61	54.80	556.11	302.93	112.27	37.06
Cl^-	40.00	720.00	198.64	152.75	76.90	30.00	1050.00	183.16	232.16	126.76
F^-	0.45	2.24	1.23	0.44	36.00	0.42	3.60	1.47	0.78	52.97
NO_3^-	2.66	228.09	55.00	59.63	108.42	2.21	143.06	41.11	37.01	90.04
SO_4^{2-}	8.00	120.00	29.64	24.56	82.89	6.00	320.00	35.74	69.41	194.23
Na^+	26.63	286.80	110.00	67.51	61.38	19.80	189.93	96.91	49.18	50.74
K^+	1.20	21.07	5.35	5.40	100.94	1.05	22.89	5.04	5.86	116.46
Ca^{2+}	16.00	496.00	97.82	106.16	108.53	40.00	488.00	115.79	103.15	89.09

Mg^{2+}	9.72	68.07	37.13	15.33	41.28	4.86	213.93	34.80	45.85	131.74
TH	139.98	1279.98	389.04	253.09	65.06	139.98	2099.64	432.57	433.01	100.10

Table. 5 Statistical Summary of groundwater seasonal physicochemical parameters composition in 2019

Water quality parameter	**Pre-monsoon - 2019**					**Post-monsoon- 2019**				
	Min	**Max**	**Mean**	**SD**	**CV**	**Min**	**Max**	**Mean**	**SD**	**CV**
P^H	7.27	10.59	8.07	0.74	9.13	7.22	8.74	7.78	0.41	5.31
EC	666.00	5200.00	1509.81	961.31	63.67	339.00	1530.00	958.75	364.27	37.99
TDS	426.24	3328.00	966.28	615.24	63.67	216.96	979.20	613.60	233.13	37.99
CO_3^{2-}	0.00	60.00	8.57	16.40	191.35	0.00	20.00	4.00	7.67	191.74
HCO_3^-	90.45	807.97	322.49	154.09	47.78	110.00	490.00	269.00	102.17	37.98
Cl^-	50.00	1100.00	236.19	225.60	95.51	20.00	230.00	108.50	52.58	48.46
F^-	0.74	1.95	1.32	0.36	27.39	0.16	2.99	1.06	0.68	64.02
NO_3^-	7.53	174.95	55.79	45.83	82.15	3.50	191.33	59.75	60.31	100.93
SO_4^{2-}	13.00	199.00	38.76	41.30	106.54	4.00	35.00	16.55	7.68	46.41
Na^+	52.56	203.15	114.75	43.60	38.00	14.02	210.90	82.22	43.78	53.24
K^+	1.04	17.49	4.91	4.79	97.63	0.96	27.00	8.64	10.20	118.04
Ca^{2+}	24.00	520.00	112.76	106.93	94.83	16.00	144.00	73.60	36.70	49.86
Mg^{2+}	4.86	213.93	53.25	45.55	85.53	4.86	63.21	30.87	14.13	45.77
TH	79.99	2179.64	500.86	442.44	88.33	139.96	539.89	310.95	128.89	41.45

Table. 6 Statistical Summary of groundwater seasonal physicochemical parameters composition in 2020

Water quality parameter	Pre-monsoon - 2020					Post-monsoon- 2020				
	Min	Max	Mean	SD	CV	Min	Max	Mean	SD	CV
P^H	7.42	449.00	287.36	7.42	449.00	7.18	8.35	7.92	0.30	3.81
EC	9.08	4377.00	2801.28	9.08	4377.00	389.00	4644.00	1572.60	1126.03	71.60
TDS	7.86	1365.67	874.03	7.86	1365.67	248.96	2972.16	1006.46	720.66	71.60
CO_3^{2-}	0	20	3	5.48	182.77	0.00	10.00	2.00	3.83	191.74
HCO_3^-	130.00	50.00	0.49	0.18	8.00	130.00	620.00	324.50	134.42	41.42
Cl^-	590.00	1010.00	2.40	199.31	180.00	30.00	1000.00	246.00	266.57	108.36
F^-	360.56	192.22	1.24	39.52	27.42	0.34	1.99	1.10	0.44	39.97
NO_3^-	121.68	219.67	0.55	50.40	38.42	0.30	528.82	96.27	126.51	131.41
SO_4^{2-}	33.75	114.28	44.18	127.54	140.12	6.75	178.25	37.13	38.68	104.19
Na^+	130.00	50.00	0.49	0.18	8.00	17.80	224.00	106.64	62.40	58.51
K^+	590.00	1010.00	2.40	199.31	180.00	1.44	24.90	6.93	5.70	82.22
Ca^{2+}	360.56	192.22	1.24	39.52	27.42	24.00	592.00	144.80	143.69	99.24
Mg^{2+}	121.68	219.67	0.55	50.40	38.42	9.72	150.72	47.65	34.88	73.21
TH	33.75	114.28	44.18	127.54	140.12	159.96	1879.84	549.92	472.98	86.01

Table. 7 Groundwater's physicochemical characteristics and a comparison table with the IS 10500: 2012 drinking water quality criteria Acceptable Limit (AL) and Permissible Limit (PL).

Water quality parameter	BIS Standards (IS 10500: 2012 & 2015)	Percentage of groundwater sample locations exceeded the drinking water quality standards											
	Acceptable-Permissible	2018				2019				2020			
		Pre-monsoon		Post-monsoon		Pre - monsoon		Post-monsoon		Pre - monsoon		Post-monsoon	
		AL	PL	AL	PL	AL	PL	AL	PL	AL	PL	AL	PL
P^H	6.5 to 8.5 - No	5	-	-	-	10	-	5	-	5	-	-	-

	relaxation												
EC	700 - 3000	85	-	80	5	95	5	70	-	80	5	70	10
TDS	500 - 2000	80	-	75	5	85	5	65	-	80	5	70	10
CO_3^{2-}	100 (WHO)	-	-	-	-	-	-	-	-	-	-	-	-
HCO_3^-	200-500 (WHO)	75	5	80	5	80	5	70	-	80	10	60	5
Cl^-	250 - 1000	10	-	10	5	10	5	-	-	10	5	10	5
F^-	1-1.5	65	15	65	45	80	25	30	15	55	20	50	10
NO_3^-	45 - No relaxation	30	-	35	-	45	-	20	-	20	-	40	-
SO_4^{2-}	200 - 400	-	-	5	-	-	-	-	-	-	-	-	-
Na^+	200 - 600 (WHO)	10	-	-	-	5	-	5	-	10	-	10	-
K^+	10 - 12 (WHO)	10	10	5	5	10	10	25	20	10	10	15	10
Ca^{2+}	75 - 200	20	5	50	10	35	5	35	-	40	5	50	10
Mg^{2+}	30 - 100	60	-	20	5	55	5	40	-	55	5	50	5
TH	200 - 600	85	10	90	15	75	5	75	-	80	5	70	10

The Table 7 shows summarized observations by comparing the analyzed physicochemical parameters with the BIS 10500:2012 drinking water quality standards. The concentration of hydrogen and hydroxyl ions is measured in terms of pH range. The pH value shows the acidity or alkalinity of water, expressed on a scale from 0 to 14. A pH of 7 is considered neutral, values below 7 are acidic, and values above 7 are alkaline. Urban areas often have increased impervious surfaces such as roads, pavements, and buildings, which changes the natural pH balance of the groundwater due to runoff containing chemicals like concrete leachates or acidic rainwater. In the pre and post-monsoon seasons of 2018, 1029, and 2020, the values of pH in current analysis are within the acceptable limit for the majority of the locations and moderately alkaline in nature. The ideal concentration of soluble substances in the groundwater establishes its suitability for human consumption**.** The quantity of dissolved ions in water is closely correlated with its electrical conductivity, which is a measure of its capacity to conduct an electrical current. Higher EC values are evidence of elevated ion or dissolved salt concentrations. A large shift in conductivity values suggests a change in the water's quality, the presence of toxins, or the presence of some sort of pollution in the vicinity. High concentration of Electrical conductivity is observed in both pre and post monsoon seasons for all the three years. The percentage of sample locations that exceeded the acceptable limit of drinking water standards of EC are 85% (2018), 95% (2019) and 80% (2020) in pre monsoon season and 80% (2018), 70% (2019) and 70% (2020) in post monsoon seasons respectively. TDS or Total Dissolved Solids, measures the total amount of dissolved organic and inorganic materials in water, including metals, salts, minerals, and other chemicals. Elevated TDS levels can affect the water taste and its suitability for specific uses.

In the pre-monsoon season the sample locations that exceeded the TDS acceptable limit was 80% (2018), 85% (2019), and 80% (2020), accordingly, and 75% (2018), 65% (2019), and 70% (2020) in the post-monsoon season. Urbanization can introduce various pollutants and contaminants to the groundwater, such as salts from de-icing agents, industrial discharges, storm water runoff carrying heavy metals, and wastewater effluents. These can lead to elevated EC and TDS levels in urban groundwater. Carbonate (CO_3^{2-}) and Bicarbonate (HCO_3^-) are forms of alkalinity in water. The presence of carbonate and bicarbonate in urban groundwater is affected by human activities, including the use of cement and concrete, as well as the release of CO_2 from industrial sources. In the present analysis Carbonate concentration at all the sample locations are within the drinking water quality standards. Bicarbonate concentration has been increased in pre-monsoon season and the samples percentages beyond the acceptable limit are 75% (2018), 80% (2019) and 80% (2020). In post-monsoon season sample percentages that are above the acceptable limit of Bicarbonate concentration are 80% (2018), 70% (2019), and 60% (2020). Chloride is an anion commonly found in groundwater. High chloride levels can indicate contamination. Chloride pollution in urban areas is a common environmental issue that arises primarily from human activities. Chloride ions (Cl-) are introduced into the environment through various sources, and their accumulation can lead to adverse effects on water quality, ecosystems, and infrastructure. With the exception of 10% of the sample locations for all the three years throughout the pre and post-monsoon seasons, the concentration of chloride in the current study is within acceptable limits.

Fluoride pollution in urban areas can occur due to various human activities and natural sources. While fluoride is an essential mineral in small quantities for dental health, excessive fluoride levels in drinking water can cause health issues, particularly dental and skeletal fluorosis. The main sources and causes of fluoride pollution in urban areas are domestic and industrial wastewater discharges, water treatment practices, agricultural practice and urban storm water runoff. In this study most of the sample locations have recorded higher levels of fluoride in both the seasons. Fluoride concentration has been increased in pre-monsoon season and the samples percentage beyond the acceptable limit are 65% (2018), 80% (2019) and slightly decreased to 55% in 2020. In the pre-monsoon season the percentage of sample locations that exceeded the Fluoride acceptable limit are 65% (2018), 30% (2019), and 50% (2020) and it is observed that about 45% of the sample locations exceeded the permissible limit of Fluoride content in the year 2018, post-monsoon season. Urbanization can lead to increased nitrate levels in groundwater as a result of using fertilizers in parks, gardens, and other landscapes, as well as from septic system effluents and wastewater discharge. High nitrate levels in drinking water can be particularly harmful to infants and pregnant women, as excessive nitrate consumption can cause methemoglobinemia (also known as "blue baby syndrome"), a condition that impairs the blood's ability to carry oxygen. In the current study Nitrate pollution is significant in the analyzed sample locations and the percentage of sample locations that exceeded the Fluoride acceptable limit are 30% (2018), 45% (2019), and 20% (2020). The percentage of sample locations that exceeded the Fluoride acceptable limit in post-monsoon season are 35% (2018), 20% (2019), and 40% (2020). Industrial discharges and the use of sulfate-containing products can elevate sulfate levels in urban groundwater. High levels of sulphate can affect the taste of water and have laxative effects. Sulphate levels at all most all sampling locations for all the three years are within the acceptable limit as per the water quality criteria for drinking in the pre and post monsoon seasons. Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Total Hardness (TH): These cations are commonly found in urban groundwater due to geological sources and human activities such as road salt application, water softener usage, and industrial discharges. The sodium and potassium concentrations for the three years 2018, 2019, and 2020 in the current study are primarily within the drinking water quality guidelines of pre and post-monsoon seasons. Unlike other pollutants, high calcium levels in water generally do not pose significant environmental or public health risks. Calcium is a beneficial mineral and an essential component of a healthy diet. It is only when calcium levels reach extremely high concentrations that it could potentially cause some issues, such as scaling in water pipes or interfering with the

performance of certain water treatment processes. A significant increase in Calcium levels is noted from pre-monsoon to post-monsoon seasons for all the years. The samples percentage beyond the acceptable limit of Calcium in pre-monsoon season are 20% (2018), 35% (2019) and 40% (2020). In post-monsoon season sample percentages that are above the acceptable limit of Calcium concentration are 50% (2018), 35% (2019), and 50% (2020). Magnesium is not typically considered a pollutant at normal concentrations. However, extremely high magnesium levels in water could cause taste and odor issues, and it may contribute to water hardness. High calcium and magnesium ion concentrations in the water can cause hardness and cause scaling in pipes and appliances. From pre-monsoon to post-monsoon Magnesium levels are decreased during the years from 2018 to 2020. The percentage of samples exceed the Magnesium acceptable limit in pre-monsoon season are 60% (2018), 55% (2019) and 55% (2020). In post-monsoon season sample percentages that are above the acceptable limit of Magnesium concentration are 20% (2018), 40% (2019), and 50% (2020) and from 2018 to 2020 there has been an increase in Magnesium concentration in post monsoon season.
Total Hardness pollution in urban areas can be a significant concern, especially when caused by human activities and land use practices. Total Hardness refers to the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in water, typically expressed in milligrams per liter (mg/L) of calcium carbonate ($CaCO_3$) equivalent. Ca^{2+} and Mg^{2+} ions are the primary contributors to water hardness. Additionally, higher concentrations of Mg^{2+} can have a laxative, cathartic, and diuretic effect (WHO 2004). Hardness of water is commonly expressed as Total Hardness (TH), a critical water quality parameter that can influence various aspects of water use and infrastructure. For drinking and domestic purposes, water hardness is an essential characteristic. According to research by Durvey et al. (1991), prolonged exposure to excessively hard water may increase the risk of developing anencephaly ,urolithiasis,various types of cancer, meternal mortality, and cardiovascular diseases. Addressing Total Hardness pollution in urban areas, water quality can be improved, infrastructure longevity can be extended, and the environmental impact and human health risks can be minimized. During the pre-monsoon season, the percentage of sample locations that exceeded the acceptable limit of drinking water quality standards for Total Hardness in the current analysis was 85% in 2018, 75% in 2019, and 80% in 2020 and in the post-monsoon season it was 90% in 2018, 75% in 2019, and 70% in 2020. The groundwater at all the sample locations is classified according to its Total Hardness and the Percentage of groundwater sample locations fall under different category for pre and post monsoon seasons of 2018, 2019 and 2020 are presented in the Table 8. According to the results presented in Table 8, it can be observed that among the 20 locations analyzed, the percentage of groundwater samples falling under the Hard Water category during the pre-monsoon season was 50% in 2018, 30% in 2019, and 30% in 2020. Similarly, for the post-monsoon season, the percentages were 45% in 2018, 50% in 2019, and 35% in 2020. During the pre-monsoon season, the percentage of groundwater samples categorized as Very Hard Water are 40% in 2018, 65% in 2019, and 65% in 2020 and for the post-monsoon season, the corresponding percentages are 50% in 2018, 40% in 2019, and 65% in 2020. About 90% of groundwater samples analyzed are classified as Hard Water and Very Hard Water in this study and only 10% of water is classified as moderately hard for the years 2018 and 2019 for both the seasons. In this study, only 5% of the groundwater samples have been classified as moderately hard in the pre-monsoon season of 2020, whereas about 95% of the samples are classed as hard or very hard water. About 100% of groundwater samples analyzed in this study during the post-monsoon season of 2020 are categorized as Hard Water and Very Hard Water.

Table. 8 Classification of groundwater according to its Total Hardness (Sawyer and McCarty. 1967, Vetrimurugan et al. 2013)

Total Hardness concentration as mg/L as $CaCO_3$	**Water Classification**	**Percentage of groundwater sample locations**					
		2018		**2019**		**2020**	
		Pre-monsoon	**Post-monsoon**	**Pre-monsoon**	**Post-monsoon**	**Pre-monsoon**	**Post-monsoon**
<75	Soft water	-	-	-	-	-	-
75 - 150	Moderately hard	10	5	5	10	5	-
150 - 300	Hard water	50	45	30	50	30	35
> 300	Very hard	40	50	65	40	65	65

Water Quality Index (WQI) Calculation

The Water Quality Index (WQI) was computed using IS 10500: 2012 drinking water quality criteria standards established by the Bureau of Indian Standards. The weights and unit weights assigned to all the physicochemical parameters for the water quality index calculation are provided in Table 2. Estimated values and acceptable limits were utilized, along with Vn and Sn values to calculate the quality rating for each parameter. The qn value was then determined using Equation 2. Subsequently, the Water Quality Index for all parameters was computed using the formula mentioned in Equation 1. The quality rating of groundwater is computed by means of the WQI score, which categorizes the water into different classes. This classification helps in quickly understanding the overall quality of groundwater based on the WQI score, with lower scores indicating better water quality and higher scores suggesting a decline in water quality, and WQI scores above 300 being considered unsuitable for drinking purposes. Water Quality Index method based Groundwater quality rating is presented in the Table 9 and the Groundwater quality status based on WQI classification of Hyderabad City for the years 2018, 2019 and 2020 in Pre and Post-monsoon seasons are presented in the Table 10, 11 and 12 accordingly.

Table 9. Water Quality Index method based Groundwater quality rating (Ramakrishnalah et al. 2009; Ketata-Rokbani et al. 2011)

WQI Value	**Rating of Water Quality**	**Grading**
< 50	Excellent	A
50 - 100	Good	B
100 - 200	Poor	C
200 -300	Very Poor	D
> 300	Unsuitable for Drinking	E

Table. 10 Water Quality Index (WQI) and status of Groundwater quality for the year 2018 in Pre and Post-monsoon seasons

S. No	**Lat**	**Long**	**2018_Pre - Monsoon**		**2018_Post - Monsoon**	
			WQI	**Groundwater**	**WQI**	**Groundwater**

				Quality Status		Quality Status
1	17.44233	78.44392	62.19	Good	81.72	Good
2	17.39764	78.44525	43.04	Excellent	92.26	Good
3	17.374	78.437	101.24	Poor	104.13	Poor
4	17.333	78.484	84.28	Good	115.83	Poor
5	17.381	78.485	74.39	Good	70.38	Good
6	17.441	78.509	81.73	Good	132.7	Poor
7	17.385	78.474	80.02	Good	110.13	Poor
8	17.361	78.508	97.81	Good	76.37	Good
9	17.494	78.508	165.68	Poor	95.66	Good
10	17.47	78.45	121.78	Poor	88.4	Good
11	17.47	78.4	200.30	Very Poor	166.69	Poor
12	17.481	78.397	36.95	Excellent	41.84	Excellent
13	17.449	78.535	128.69	Poor	168.1	Poor
14	17.53	78.42	98.03	Good	87.45	Good
15	17.5	78.46	78.87	Good	106.7	Poor
16	17.54	78.44	98.53	Good	98.53	Good
17	17.43	78.368	84.55	Good	46.14	Excellent
18	17.316	78.405	221.75	Very Poor	368.93	Unsuitable for Drinking
19	17.52583	78.27017	76.22	Good	64.71	Good
20	17.5091	78.3003	87.98	Good	83.65	Good

Table. 11 Water Quality Index (WQI) and status of Groundwater quality for the year 2019 in Pre and Post-monsoon seasons

S. No	**Lat**	**Long**	**2019_Pre - Monsoon**		**2019_Post - Monsoon**	
			WQI	**Groundwater Quality Status**	**WQI**	**Groundwater Quality Status**
1	17.44233	78.44392	86.39	Good	78.81	Good
2	17.39764	78.44525	121.30	Poor	99.57	Good
3	17.374	78.437	114.35	Poor	80.42	Good
4	17.333	78.484	109.33	Poor	32.67	Excellent

5	17.381	78.485	63.77	Good	78.68	Good
6	17.441	78.509	87.19	Good	147.45	Poor
7	17.385	78.474	112.73	Poor	84.31	Good
8	17.361	78.508	86.73	Good	85.75	Good
9	17.494	78.508	116.86	Poor	140.63	Poor
10	17.47	78.45	71.95	Good	90.70	Good
11	17.47	78.4	90.71	Good	54.51	Good
12	17.481	78.397	71.25	Good	104.18	Poor
13	17.449	78.535	144.99	Poor	154.55	Poor
14	17.53	78.42	107.86	Poor	85.74	Good
15	17.5	78.46	108.50	Poor	94.77	Good
16	17.54	78.44	94.82	Good	57.95	Good
17	17.43	78.368	150.71	Poor	82.32	Good
18	17.316	78.405	373.39	Unsuitable for Drinking	125.17	Poor
19	17.52583	78.27017	90.79	Good	40.68	Excellent
20	17.5091	78.3003	114.34	Poor	75.43	Good

Table. 12 Water Quality Index (WQI) and status of Groundwater quality for the years 2020 in Pre and Post-monsoon seasons

S. No	**Lat**	**Long**	**2020_Pre - Monsoon**		**2020_Post - Monsoon**	
			WQI	**Groundwater Quality Status**	**WQI**	**Groundwater Quality Status**
1	17.44233	78.44392	115.31	Poor	106.89	Poor
2	17.39764	78.44525	111.93	Poor	41.81	Excellent
3	17.374	78.437	111.75	Poor	151.95	Poor
4	17.333	78.484	97.19	Good	48.8	Excellent
5	17.381	78.485	78.24	Good	81.11	Good
6	17.441	78.509	90.06	Good	161.15	Poor
7	17.385	78.474	86.85	Good	129.63	Poor
8	17.361	78.508	86.02	Good	106.48	Poor
9	17.494	78.508	86.82	Good	143.64	Poor
10	17.47	78.45	160.7	Poor	108.55	Poor

			2			
11	17.47	78.4	39.43	Excellent	48.96	Excellent
12	17.481	78.397	141.18	Poor	44.73	Excellent
13	17.449	78.535	67.76	Poor	428.2	Unsuitable for Drinking
14	17.53	78.42	85.52	Good	80.43	Good
15	17.5	78.46	135.92	Poor	119.31	Poor
16	17.54	78.44	132.34	Poor	149.41	Poor
17	17.43	78.368	112.55	Poor	88.92	Good
18	17.316	78.405	363.39	Unsuitable for Drinking	289.95	Very Poor
19	17.52583	78.27017	93.05	Good	88.290	Good
20	17.5091	78.3003	103.18	Poor	100.620	Poor

The annual average rainfall in Hyderabad for the years 2018, 2019, and 2020 was 754.8 mm, 1150.8 mm, and 1284.9 mm respectively, indicating an overall increase in rainfall over these years, with significant increases observed in both the pre-monsoon and post-monsoon seasons (source: IMD Hydro). Rainfall, both low and high, significantly influences groundwater quality. Low rainfall generally leads to increased contaminant concentration, reduced recharge, higher extraction rates, and increased contamination risk. High rainfall can improve groundwater quality through dilution and enhanced recharge but it also poses risks of leaching and flooding induced contamination. In the pre-monsoon season of 2018, the Water Quality Index (WQI) in this analysis is in the range of 36.95 to 221.75. 10% of the samples fell into the excellent category based on the WQI categorization of groundwater quality. Approximately 60% of the samples were classified as good, 20% as poor, and 10% as very poor. In the post-monsoon season of 2018, the water quality index values ranged from 41.84 to 368.93. According to WQI classification, 10% of the groundwater samples were in the excellent category. Around 50% of the samples were rated as good, 35% as poor, and 5% were deemed unsuitable for drinking. In the pre-monsoon season of 2019, the water quality index in the study area varied from 63.77 to 373.39. Among groundwater samples, none were rated as excellent, 45% were considered good, 50% fell into the poor category, and 5% were deemed unsuitable for drinking. During the post-monsoon season of the same year, water quality index values ranged from 32.67 to 154.55. Here, 10% of groundwater samples were rated as excellent, 65% as good, and 25% as poor. In the pre-monsoon season of 2020, the water quality index in the study area ranged from 39.43 to 363.39. With respect to WQI classification, 5% of groundwater samples were rated as excellent. Approximately 40% were classified as good, 50% as poor, and 5% were deemed unsuitable for drinking. During the post-monsoon season of the same year, water quality index values varied from 41.81 to 428.20. Here, 20% of groundwater samples were classified as excellent according to the WQI. Around 20% were rated as good, 50% as poor, 5% as very poor, and another 5%

were considered unsuitable for drinking. According to the WQI classes and their suitability, groundwater is of excellent quality is suitable for drinking, domestic, industrial and irrigation uses without any treatment. Groundwater is of good quality and is generally suitable for drinking with minor treatment and domestic, industrial and irrigation uses without any treatment. Groundwater is of poor quality and requires significant treatment before it can be used for drinking and other purposes. Groundwater is of very poor quality is unsuitable for consumption, residential uses and groundwater can be employed in industrial and agricultural use after appropriate treatment. Groundwater is of unsuitable for drinking category is not fit for consumption or other common residential usage. It may only be used for irrigation or industrial processes where water quality is not critical, after proper treatment**.**

Conclusion

The Hyderabad city experiences elevated stress from interactions between rock elements and groundwater, significantly influencing groundwater geochemistry. Land-use changes, particularly in unconfined aquifer areas affected by urbanization, contribute to aquifer depletion and degradation. The elevated Water Quality Index (WQI) values are attributed to increased levels of Electrical Conductivity (EC), Total Dissolved Solids (TDS), Bicarbonate (HCO_3^-), Nitrate (NO_3^-), Fluoride (F^-), Magnesium (Mg2+), Calcium (Ca2+), and Total Hardness (TH) in the groundwater, highlighting an urgent need for remedial action. Addressing the impact of urbanization on groundwater quality requires a multi-faceted approach. It involves implementing proper waste management systems, promoting sustainable urban planning practices, improving wastewater treatment infrastructure, and raising awareness among residents about the importance of responsible water use. Collaboration between government agencies, urban planners, environmental organizations, and local communities is crucial to mitigating the adverse effects of urbanization on groundwater quality. Assessing groundwater quality in Hyderabad city provides decision-makers, water resource managers, and stakeholders with a thorough understanding of the present condition of groundwater resources. This understanding enables the implementation of suitable measures to protect water quality, conserve resources, and guarantee the delivery of safe and sustainable water for the growing population of Hyderabad.

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