Hydrochemical Characteristics of Groundwater in and around the Peenya Industrial Area in Bengaluru City

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Abstract: - The present study aims to use the Water Quality Index (WQI) modeling method to know about groundwater hydrochemistry and drinking suitability in and around (5 km) the Peenya industrial area/estate in Bengaluru city. For this research study, 116 bore well samples were collected and examined for the pre (dry) and post (wet) monsoon seasons in 2021, following APHA standard procedures. According to the BIS standard, the TH, Ca, Mg, NO_3, and TDS exceed the desirable limits in both seasons. The water quality examination data shows that TDS concentration is found to be higher above the desired limit (500 mg/l) during the pre- (63%) and post- (45%) monsoon seasons. Furthermore, 55% (pre-monsoon) and 15% (post-monsoon) of the groundwater samples exceed the BIS's nitrate allowable limit (45 mg/l). Among the analyzed samples, the calcium content in 19% and 20% of samples exceeded the desirable limit (75 mg/l), and magnesium content in 87% and 83% exceeded the desirable limit (30 mg/l) in pre- and post-monsoon seasons. In 95% of samples, TH content exceeded the desirable limit (200 mg/l) in both pre- and post-monsoon seasons. Piper diagram plots were utilized to determine sources of dissolved constituents, rock-water interaction, and other factors that influenced the region's groundwater composition. Based on hydro-chemical facies the Ca-Mg-HCO_3 type of water predominates in the study area during pre (dry) and post (wet)-monsoon seasons of the year 2021. The chemistry of groundwater has deteriorated significantly because of several industrial and anthropogenic activities. The WQI spatial distribution map shows that groundwater quality has the greatest impact in the west and a few places in the north and south regions of the research area. This study was conducted in Bangalore's Peenya industrial area to determine whether groundwater is suitable for drinking, identify the mechanisms governing groundwater's geochemistry, and evaluate the effects of an industrial area on groundwater quality. The primary focus of this study is the major ion chemistry in this field.

Key-Words: - Groundwater, Hydrochemistry, Drinking suitability, Peenya industrial area, India.

Received: March 23, 2023. Revised: October 19, 2023. Accepted: December 13, 2023. Published: December 31, 2023.

1 Introduction

Groundwater is a vital natural resource that meets our rural and urban needs. Bengaluru is one of the most economically fast-growing cities in the south zone of Karnataka, dominated by intense growth of small- and large-scale industrial activities. 40 sq. km lies in the North part of Bengaluru city and contains around 2100 industries, the majority of which are chemical, leather, pharmaceutical, plating, polymer, and allied industries. The industrial estate is fully surrounded by private and residential mixed industrial activity. The Peenya industrial area/estate uses groundwater mostly for domestic, industrial, and drinking uses. Demand for groundwater in big cities like Bengaluru is increasing. Therefore, human health is directly impacted by the quality of groundwater. Between the authorized Peenya Industrial land/estate and the area around it, there is no existing buffer zone.

Several investigations were done inside the industrial estate to determine the levels of pollution, but none were done outside of it to identify the contaminated bore water or the factors that significantly contribute to pollution due to runoff from the industrial estate. To prevent further groundwater contamination concerns that influence public health and related health issues, continual monitoring and assessment of water quality are necessary both inside and outside the Peenya Industrial Area, [1], [2].

The interaction between surface water, groundwater, and aquifer minerals, leaching of industrial activities from the surface, and other human activities are among the geogenic and anthropogenic variables that contribute to the variance in groundwater quality. Groundwater's chemical makeup varies as a result, changing over time. Additionally, the parent rock, the rate of weathering, the length of stay, and environmental elements like temperature and precipitation all play a role. Groundwater's major and minor ion concentration is regulated by hydrogeochemical processes such as weathering, dissolution, mixing, and ion exchange. Industrial locations are susceptible to pollution from effluents with complicated compositions. In the vicinity of these industrial facilities, major ions and heavy metals are frequently the most common pollutants. The chemical ions found in groundwater because of these factors dictate whether it is suitable for industrial and drinking uses, [3], [4].

WQI is a helpful mathematical technique for assessing groundwater quality for drinking. This concept of WQI was developed and proposed first by Horton. WQI represents a single number that is easily understood by the public and decision-makers, [5]. Geographic information system (GIS) is computer-based technology employed to illustrate the spatial-temporal distribution of groundwater characteristics, [6]. The main advantage of GIS is that it handles huge amounts of data, simplifies the understanding of complex data, and facilitates quick judgments through graphical representations, [7]. GIS also offers the ability to decide and present precise information. Considering the foregoing background information, the current investigation study aimed to (1) determine the suitability of the groundwater in and around (5 km) the Peenya industrial area using the WQI model for both the pre- and post-monsoon period; and (2) to discuss hydrochemistry combined with a Geographic Information System (GIS) to suggest groundwater management strategies.

2 Study Area

Peenya Industrial area/estate in Bengaluru, Karnataka, India is one of the largest and oldest industrial Areas in Southeast Asia. The study area taken lies between latitude 13^0 1’ 42" N and longitude 77^0 30’ 45" E. It was established in the late 1970s by the Karnataka Small Industries Development Corporation as Stage I, II III, and Phase IV. The total extent of the area/estate is about 40 sq. km and is in the north-western suburbs of Bengaluru city, Figure 1. The main industries in the Peenya industrial area/estate are Galvanizing, Degreasing, Spray painting, Powder coating process, Pickling, Phosphating, Anodization, Textile Dying, Garment Washing, Electroplating, Lead Processing, and Pharmaceuticals Formulations, etc. The Peenya Industrial Area is recognized by both the Central and State Governments as the main hub of industrial activity in the State and an important source of manufactured goods with a reputation for quality for both domestic and export markets. The study area's geology is a component of the Peninsular Gneissic Complex, which is represented by biotite, granodioritic, and mafic gneiss with intrusive rocks such as pegmatites and dykes. The industrial area /estate in general is witnessed by red sandy soil, [2]. The soil cover extends up to 1 to 2 meters below the ground level. The peninsular gneissic group, which includes the granites, gneisses, and migmatites, is responsible for most of the aquifers in Bengaluru's urban regions. Igneous and metamorphic rocks combine to form migmatite rock. The area's weathered zone and the freshly formed gneisses and granite rock beneath it make up the aquifer system. The northern part of Bengaluru has phreatic groundwater. Over the previous 50 years, the research region received 923 mm of yearly rainfall on average. Groundwater depths before and during the monsoon season vary from 0 to 49.95 metres, and from 0.20 to 58.97 metres, respectively NGRI, [8]. The industrial area is located on an extremely undulating terrain. The highly undulating topography with a sub-dendritic nature has given rise to the origin of several micro watersheds with varying hydrological characteristics as per NGRI, [8].

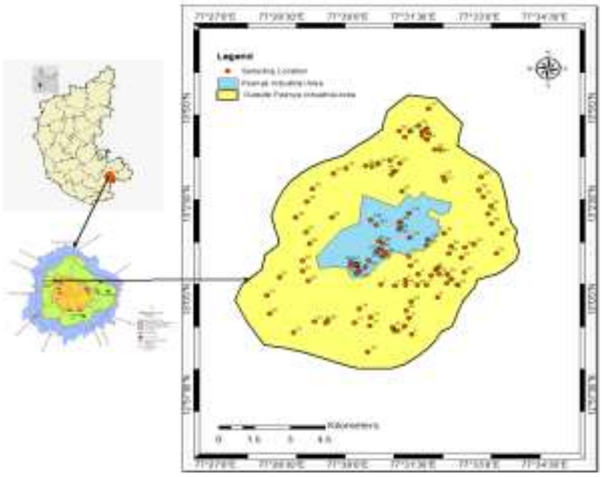

Fig.1: Location map of the study area with groundwater sampling points

2.1 Methodology

A total of 116 Groundwater samples were collected from both in and around (5KM) Peenya industrial area, Figure 1 during the pre and post-monsoon period (March 2021). 30 samples from inside the Peenya industrial area and 86 samples from the surrounding Peenya industrial area/estate within a 5km distance from the boundary of the Peenya industrial area were collected. The collected bore well samples were transferred into a washed polyethylene bottle for analysis of physio-chemical characters. The bore well Sampling point's coordinates were noted using GPS. Once collected, each water sample was securely stored before being sent to the Environmental Engineering lab for analysis. The collected groundwater samples were tested for pH, EC, chlorides, total alkalinity, total dissolved solids, magnesium, calcium, iron, fluoride, total hardness, potassium, sodium, bicarbonates, sulfates, and nitrate using the standard procedures recommended by APHA-2005 guidelines, [9]**.** The obtained test results were compared to the recommended standard allowable levels as per the standards recommended by the Bureau of Indian Standards (BIS:10500, 2012), [10]. The analytical data obtained can be used for calculating WQI, plotting piper-tri-linear diagrams, Box-and-whisker plots, and spatial distribution maps.

2.2 WQI Calculations

The WQI provides an accurate representation of surface and groundwater quality for most domestic uses. WQI is defined as a rating that represents the combined impact of several water quality factors.

The groundwater quality of the study area is determined using a most effective mathematical tool known as the Water Quality Index (WQI). WQI provides a single indicator value that represents water quality by integrating different water quality variables, [11], [12], [13].

WQI estimations include the following successive steps, [14], [15], [16]. The **first step** is "assigning weight": each of the 11 parameters has been assigned a weight (wi) according to its relative importance based on the quality of groundwater for domestic purposes as shown in Table 1. In the weights assigned between 1 and 5, the most significant parameters have been provided with a greater value and the least significant have been assigned a lower value. The **second step** is the "relative weight" (Wi): which is computed from the following arithmetic index formula

$$W_i = \frac{w_i}{\sum w_i}$$

Where W_i is the relative weight, is the ratio of weight given for each parameter to the summation of weightage of all the parameters. The w_i is the weight of each parameter. The calculated relative weight (W_i) values of each physico-chemical parameter are given in Table 3.

The **third step** is "quality rating scale calculation (qi)": Using the BIS drinking water standard, [10], each parameter's quality rating scale is determined by dividing its concentration in each water sample (Ci) by the corresponding standard (Si), and then multiplying the result by 100:

$$q_i = (C_i / S_i) \times 100$$

Finally, the W_i and qi are used to calculate the SI_i for each chemical parameter, where SI_i is the sub-index of each parameter and then it is used to calculate WQI as shown below:

$$SI_i = W_i \times qi$$

$$WQI = \sum SI_i$$

Table 1. Relative weightage of physicochemical parameters

Sl No	Paramater	Weight (w_i)	Relative Weight (Wi)	BIS:10500 (2012)
1	pH	4	0.11111	6.5-8.5
2	Chlorides,mg/l	3	0.08333	250
3	Total hardness,mg/l	2	0.05556	200
4	Iron, mg/l	4	0.11111	0.3
5	Nitrate, mg/l	5	0.13889	45
6	Calcium,mg/l	2	0.05556	30
7	Magnesium, mg/l	2	0.05556	75
8	Total dissolved solids, mg/l	4	0.11111	500
9	Fluoride, mg/l	4	0.11111	1-1.5
10	Sulphates, mg/l	4	0.11111	200
11	Total alkalinity,mg/l	2	0.05556	200
		$\sum w_i$ =36	$\sum Wi$ =1.0000	

3 Results and Discussion

Table 2 shows the statistics of groundwater quality parameters in the pre and post-monsoon seasons of 2021. The pH ranges of the water samples in the current investigation were 5.1 to 8.1 and 7.8 to 8.8 in the pre and post-monsoon seasons, respectively. It was observed that 97% and 91% of samples fall within the desirable pH limit of 6.5 to 8.5 mg/l. The pH value of water is a crucial indication of water quality. Although pH has no direct impact on human health, changes in pH have an impact on several biological processes as well as some psychological impacts, [17]. The chloride value is specified as 250-1000 mg/l as per BIS 10500 standards. The study area's 35% and 3% chloride concentration values are beyond the acceptable limit in pre-/post-monsoon. Excessive levels of chloride in the water are indicators of pollution and are used as an indicator for groundwater contamination caused by industrial and human waste. Drinking water with higher chloride content has a salty taste and a laxative effect, [18]. The TH concentration limit is 200 mg/l to 600 mg/l as per the BIS Standards. It was observed that 95% of water samples are beyond the acceptable limit in both seasons. water above 300 mg/l is considered hard. Soap consumption by hard water represents an economic loss to the water user, [19]. The calcium concentration limit in the groundwater is between 75 to 200 mg/l, it was found that 19% and 20% of samples are beyond the acceptable limit in pre-/post-monsoon. The magnesium concentration level in the groundwater is within the limit of 30 to 100mg/l as per BIS 10500 standards. From the study, magnesium samples are found 13% and 83% more than the desirable limit pre-/post-monsoon. The concentration of magnesium and calcium salts in water determines its overall hardness. The salts of calcium, together with those of magnesium are responsible for the hardness of water. In the current investigation, the concentration level of TDS is specified as 500-2000 mg/l as per BIS 10500 standards. It was observed that 63% and 45% of TDS values are beyond the acceptable limit in pre-/post-monsoon respectively. Groundwater with high TDS is of inferior palatability and may produce unfavorable physiological reactions in the transient consumer, [20]. Many of the groundwater samples are noticed with a high nitrate concentration in pre-monsoon 55% of the samples are beyond the maximum permissible limit and 15% of samples are beyond the acceptable limit in post-monsoon. It results from several industrial operations. The presence of excessive nitrate in water may adversely affect the health of infants causing blue baby disease. The iron concentration limit is 0.3 mg/l as per the BIS Standards. It was observed that 28% of water samples are beyond the acceptable limit in the post-monsoon season only. Higher iron concentrations make the water unpleasant in taste. The fluoride, and sulfate concentration levels in the groundwater samples of the entire study area fall under the desirable limits. The percentage compliance for the respective parameters measured for both seasons is shown in Table 3.

Table 2. Descriptive statistics of groundwater quality parameters in pre and post-monsoon seasons of 2021

Paramater	Pre-Monsoon			Post-Monsoon			Drinking Water Standards	
	Min	Max	Avg	Min	Max	Avg	BIS:10500 (2012)	WHO Standards 2004
pH	5.1	8.1	7.4	7.8	8.8	8.3	6.5-8.5	6.5-8.5
Cl	26.0	1361.0	246.7	22.0	320.0	107.3	250	250
TH	88.0	1740.0	468.9	124.0	1324.0	390.0	200	300
Fe	0.0	0.3	0.0	0.0	3.3	0.4	0.3	0.3
NO_3	0.0	223.0	63.9	0.0	77.0	21.1	45	50
Ca	11.2	149.1	58.3	14.4	190.8	60.0	30	100
Mg	2.9	357.7	78.6	1.9	140.9	54.4	75	50
TDS	235.0	3960.0	634.8	145.0	1462.0	497.4	500	1000
EC	0.4	3.4	1.0	482.0	2640.0	730.1	-	400
F	0.0	0.5	0.1	0.0	0.3	0.0	1-1.5	1.5
SO_4	1.1	46.4	17.4	1.0	65.7	17.7	200	400
TA	120.0	948.0	331.8	216.0	480.0	358.6	200	-
HCO_3	80.0	888.0	262.8	143.0	436.0	315.5	-	350
Na	14.0	280.0	81.1	19.0	110.0	59.7	-	200
K	0.0	19.0	6.2	2.0	15.0	5.9	-	20

All values are in mg/l except EC its µs/cm

Table 3. Methods of Estimation of physico-chemical Characteristics of groundwater quality

Sl No	Paramater	Method	BIS:10500 (2012)	Percentage Compliance	
				Pre-Monsoon	Post Monsoon
1	pH	pH meter	6.5-8.5	97	91
2	Chlorides,mg/l	Argentometric method	250	65	97
3	Total hardness,mg/l	EDTA method	200	5	5
4	Iron, mg/l	Spectrophotomete	0.3	100	72
5	Nitrate, mg/l	Ion Meter	45	45	85
6	Calcium,mg/l	EDTA method	30	81	80
7	Magnesium, mg/l	EDTA method	75	87	17
8	Total dissolved solids, mg/l	TDS Meter	500	37	55
9	Conductivity, µs/cm	Conductivity Meter	-	-	-
10	Fluoride, mg/l	Ion Meter	1-1.5	100	100
11	Sulphates, mg/l	Gravimetric Method	200	100	100
12	Total alkalinity mg/l	Volumetric Method	200	9	0
13	Bicarbonates,mg/l	Volumetric Method	-	-	-
14	Sodium, mg/l	Flame Photometer	-	-	-
15	Potassium, mg/l	Flame Photometer	-	-	-

Five categories are established from the computed WQI values, [15], [21]: "excellent water," "good," "poor," "very poor," and "water unsuitable for drinking." In the current research study, the calculated WQI values for the 116 Groundwater samples both in and around the Peenya industrial area ranged from 39.103 to 224.168 & 39.641 to 192.387 and pre-/post-monsoon season, with 4 % and 8% of the waters being “excellent water” in pre-/post-monsoon season, 59 % and 66% “good water” in pre-/post-monsoon season,36 % and 27% in “poor water” in pre-/post-monsoon season and 1% “very poor water for drinking” in pre-monsoon season (Table 4). The figured WQI values for the 30 Groundwater samples from inside the Peenya industrial area ranged from 70.57 to 196.01and pre-/post-monsoon season, with only 13 % and 7% “good water” in pre-/post-monsoon season, 83 % to 93% “poor water” in pre-/post-monsoon season and 3% “very poor water for drinking” in pre-monsoon season (Table 5). Further WQI values for the 86 Groundwater samples from outside (5km) Peenya industrial area ranged from 70.57 to 196.01and and pre-/post-monsoon season, with only 6 % and 10% “excellent water” in pre-/post-monsoon season,74% and 86% “good water” in pre-/post-monsoon season, 20 % to 3% “poor water” in pre-/post-monsoon season water for drinking” (Table 6). Because of the high amounts of TDS, TH, nitrate, calcium, and magnesium from industrial activity, the Peenya industrial area has low water quality standards during the pre- and post-monsoon season respectively. In contrast, post-monsoon season outside the industrial region exhibits an improvement in water quality because of the diluting effect of rainwater. The pie chart showing the percentage of water samples based on WQI values during pre/post-monsoon-2021 is shown in Figure 2 and Figure 3.

Table 4. Water quality classification based on WQI value for both inside and outside Peenya Industrial Area

WQI Value	Water Qulity	Pre-Monsoon		Post-Monsoon	
		No of Samples	Percentage	No of Samples	Percentage
< 50	Excellent	5	4%	9	7%
50-100	Good Water	68	59%	76	66%
100-200	Poor Water	42	36%	31	27%
200-300	Very Poor Water	0	1%	0	0%
>300	Water Unsuitable for Drinking	0	0%	0	0%

Table 5. Water quality classification based on WQI value for Inside Peenya Industrial Area

WQI Value	Water Qulity	Pre-Monsoon		Post-Monsoon	
		No of Samples	Percentage	No of Samples	Percentage
< 50	Excellent	0	0%	0	0%
50-100	Good Water	4	13%	2	7%
100-200	Poor Water	25	84%	28	93%
200-300	Very Poor Water	1	3%	0	0%
>300	Water Unsuitable for Drinking	0	0%	0	0%

Table 6. Water quality classification based on WQI value for Outside Peenya Industrial Area

WQI Value	Water Qulity	Pre-Monsoon		Post-Monsoon	
		No of Samples	Percentage	No of Samples	Percentage
< 50	Excellent	3	6%	9	10%
50-100	Good Water	64	74%	74	86%
100-200	Poor Water	17	20%	3	4%
200-300	Very Poor Water	0	3%	0	0%
>300	Water Unsuitable for Drinking	0	0%	0	0%

Fig. 2: Pie chart showing the percentage of water sample based on WQI values during pre-monsoon-2021

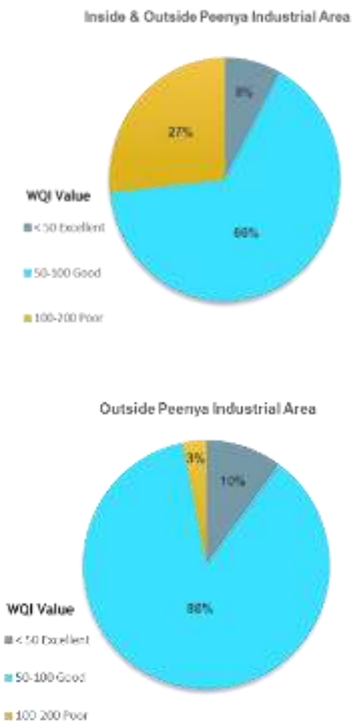

Fig. 3: Pie chart showing the percentage of water sample based on WQI values during post-monsoon-2021

The water quality at each location was shown and its acceptability for drinking was established by the WQI spatial variation map (Figure 4 and Figure 5). The maps of WQI show five different types of water quality categories: <50 excellent quality water,50-100 good water,100-200 poor water,200-300 very poor water, and >300 unsuitable for drinking purposes, [15], [21]. The region on the maps with a poor category water quality index is shown by the color yellow patches. Most of the groundwater in the poor category is found inside the Peenya Industrial Area because of the discharge of industrial wastewater. The percentage of groundwater that comes under the poor category outside the Peenya Industrial area, indicates that pollution in groundwater moved towards lower-level areas. Due to the groundwater sample sites' lower height, it is noticed that groundwater quality is determined to be in the poor category towards the west while being in the good category in the east (higher elevation).

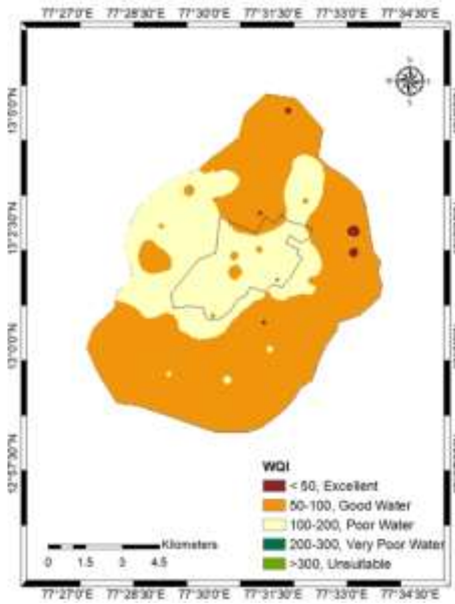

Fig. 4: Spatial distribution of WQI in pre-monsoon

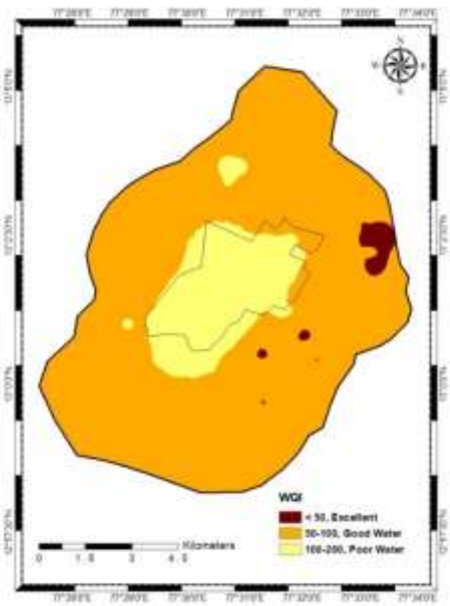

Fig. 5: Spatial distribution of WQI in post-monsoon

Figure 6, shows the elevation map of the Peenya industrial area. The pink and purple color on the elevation map indicates steeper slopes whereas orange and red colors indicate higher elevation. Figure 7, Bar graphs showing the comparison of TDS values with groundwater sampling location elevation values. It is observed that at groundwater sampling points having lower elevation values, TDS concentration is high. In groundwater sampling points having higher elevation, TDS concentration is low. This comparison study indicates that pollution in groundwater moves towards lower-level areas. The Water tables often follow the topography of the area, or upward and downward tilts and the land above them, [15]. The groundwater moves more quickly towards down steeper slopes than down shallow slopes. For this reason, it was observed that pollution migration is more towards the west direction of the study area, Figure 7. The areas which come under poor water quality. This study adds novelty to the current work because it includes investigations that have not been done before in the study field.

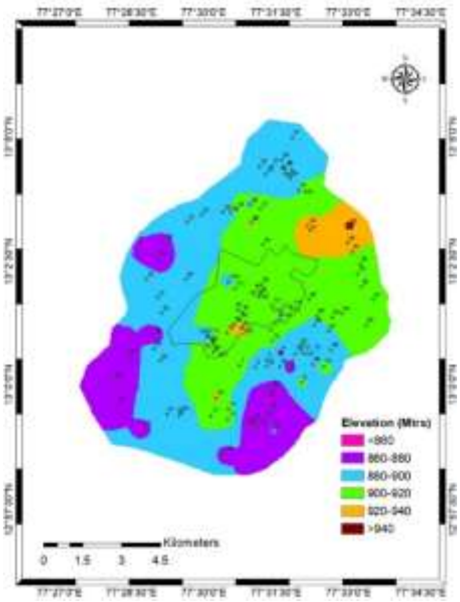

Fig.6: Map showing elevation at the groundwater sampling location

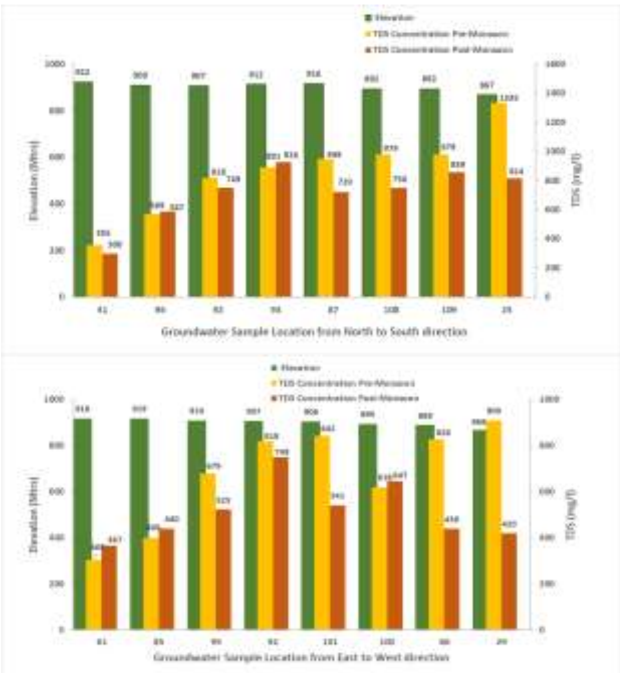

Fig.7: Bar graphs showing the comparison of TDS values with groundwater sampling location elevation values

The results from the chemical analysis of the groundwater sample were plotted using the Piper-tri-linear model, [22]. According to the ionic composition of groundwater samples, a specialized graph called the piper-tri-linear can be used to reveal chemical correlations between samples (Figure 8). Two triangle fields, one diamond-shaped field, and three distinct fields make up the Piper diagram, [23]. The cations and anions are shown in separate ternary plots. The two ternary plots are then projected onto a diamond-shaped field, from which inference is drawn based on the hydro-geochemical facies concept, [24]. The analytical results obtained from the groundwater samples are designed on a Piper trilinear diagram. Figure 9 and Figure 10, reveal the Hydrochemical regime of the study area. It identifies the water compositions and variations in ion concentrations, [25]. In pre-monsoon (Table 7), it was found that Alkaline earth (Ca+Mg) exceeds alkalies (Na+K) type is the most dominant facies in the study area (constituting 84%). Weak acids (CO_3+HCO_3) exceed Strong acids (SO_4+Cl) type (constituting 62 %) ranked second and Magnesium bicarbonate type facies ranked third in abundance (constituting 52 %). In post-monsoon (Table 7) it was Weak acids (CO_3+HCO_3) exceed Strong acids (SO_4+Cl) type is the most dominant facies in the study area (constituting 95%). Alkaline earth (Ca+Mg) exceeds alkalies (Na+K) type (constituting 93%) ranked second and Magnesium bicarbonate type facies ranked third in abundance (constituting 85 %). The investigated sample's hydrochemistry indicates that the alkaline earth > alkali metals and weak acid > strong acidic anions. The dominant hydrochemical facies of groundwater in the study area is Ca–Mg–HCO_3. In Pre-Monsoon, the diamond field of Piper shows the mixed classification of water type i.e., gypsum ground waters and drainage, shallow, fresh ground waters, and deeper ground waters influenced by ion exchange. In Post-Monsoon- the diamond field of Piper shows typical shallow, fresh ground waters nature. There is no significant change in the hydro-chemical facies noticed during the study period (pre- and post-monsoon), which indicates that most of the major ions are natural in origin. The mixed type of the other groundwater samples suggests that they are impacted by rainwater infiltration, which comparatively revealed enrichment of Mg, Cl, and HCO_3 ions, or by anthropogenic contaminations such as Mg, Cl, and Na. The reason is groundwater passing through Migmatite rock dissolves only small quantities of mineral matter because of the relative insolubility of the rock composition.

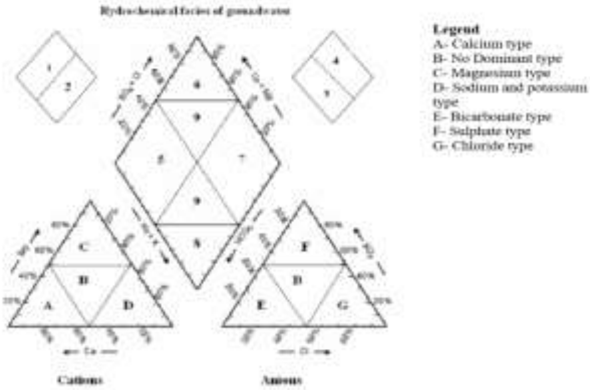

Fig. 8: Classification diagram for anion and cation facies in the form of major-ion percentages. Water types are designed according to the domain in which they occur on the diagram segments

Table 7. Characterization of groundwater in and around Peenya industrial area of Karnataka based on Piper tri-linear diagram

Subdivision of the diamond	*Characteristics of corresponding subdivisions of diamond-shaped fields*	*Percentage of samples in this category*	
		Pre-Monsoon	*Post-Monsoon*
1	Alkaline earth (Ca+Mg) Exceed alkalies (Na+K)	84.5	93.1
2	Alaklies exceeds alkaline earths	15.5	6.9
3	Weak acids (CO_3+HCO_3) exceed Strong acids (SO_4+Cl)	62.1	94.8
4	Strong acids exceeds weak acids	37.9	5.2
5	Magnesium bicarbonate type	51.0	85.3
6	Calcium-chloride type	3.4	0.9
7	Sodium-chloride type	3.4	0.9
8	Sodium-Bicarbonate type	0.0	0.0
9	Mixed type (No cation-anion exceed 50%)	42.2	12.9

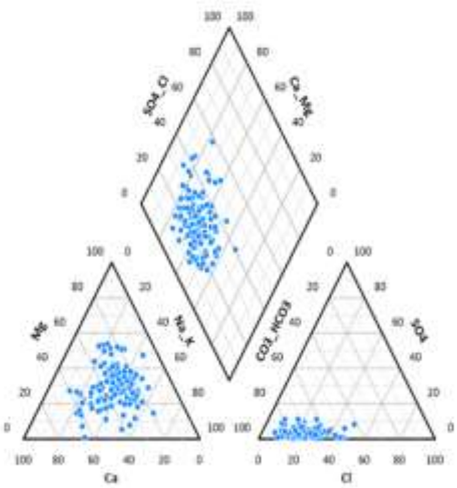

Fig. 9: Pre-monsoon groundwater samples plotted in the piper-Trilinear diagram

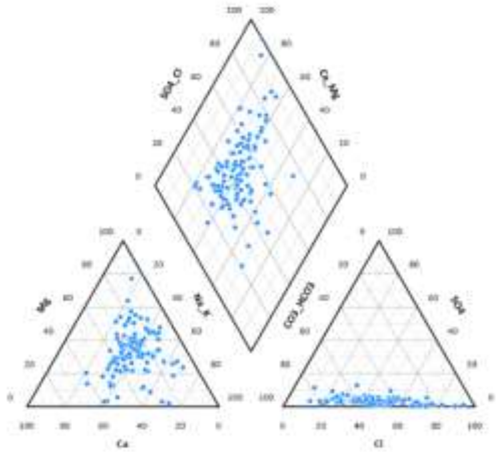

Fig. 10: Post-monsoon groundwater samples plotted in the piper-Trilinear diagram

Pearson's correlation matrix is used to measure and find the association between two variables. This simple statistical tool has been used to quantify the relationship between two variables and illustrate the extent to which one variable depends on the other, [25]. It is observed Magnesium and total hardness is found to have a very strong association both before and after the monsoon season (Table 8 and Figure 9). This interrelationship between these two variables indicates that the hardness of the groundwater is permanent. A Box and Whisker Plot was prepared in the present study. It is an appropriate way of visually displaying the data distribution through their quartiles, [25]. Groundwater samples collected in and around the Peenya industrial region over the two seasons are displayed in a box-whisker plot showing the analytical results together with their maximum, lowest, median, and percentile values (Figure 11 and Figure 12).

Table 8. Correlation matrix of various parameters analyzed in the pre-monsoon season

Parameter	pH	TDS	Cl	SO_4	NO_3	F	TH	Ca	Mg	Fe	TA
pH	1										
TDS	-0.067	1									
Cl	-0.209	0.440	1								
SO_4	0.001	0.010	-0.174	1							
NO_3	0.163	0.186	0.132	-0.050	1						
F	0.057	0.192	0.136	-0.205	0.012	1					
TH	-0.147	0.400	0.571	0.118	0.175	-0.134	1				
Ca	-0.351	0.523	0.301	-0.169	0.027	0.067	0.270	1			
Mg	-0.054	0.270	0.510	0.181	0.165	-0.150	0.948	0.031	1		
Fe	0.034	0.053	-0.001	0.110	0.266	-0.175	0.230	0.080	0.205	1	
TA	0.061	0.430	-0.025	0.476	0.115	-0.153	0.295	0.173	0.234	0.421	1

Table 9. Correlation matrix of various parameters analyzed in post-monsoon season

Parameter	pH	TDS	Cl	SO_4	NO_3	F	TH	Ca	Mg	Fe
pH	1									
TDS	-0.366	1								
Cl	-0.521	0.576	1							
SO_4	0.024	0.399	0.147	1						
NO_3	-0.037	0.375	0.131	0.162	1					
F	-0.040	0.003	0.095	0.165	-0.087	1				
TH	-0.465	0.570	0.596	0.173	0.162	0.131	1			
Ca	-0.376	0.366	0.532	0.089	0.101	0.036	0.496	1		
Mg	-0.433	0.553	0.521	0.275	0.132	0.229	0.659	0.071	1	
Fe	-0.136	0.532	0.311	0.523	0.351	0.183	0.318	0.164	0.406	1
TA	-0.261	0.270	0.149	0.120	0.075	0.033	0.227	0.064	0.425	0.158

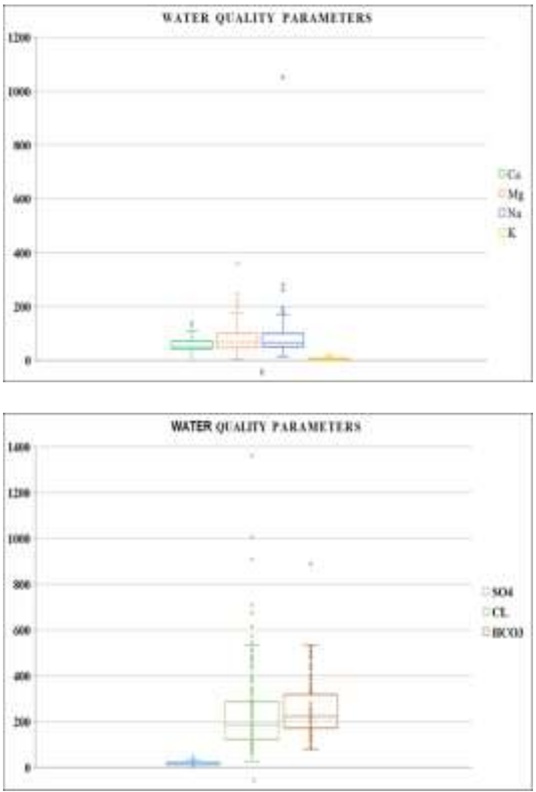

Fig. 11: Box-and-whisker plot of water quality parameters in pre-monsoon season

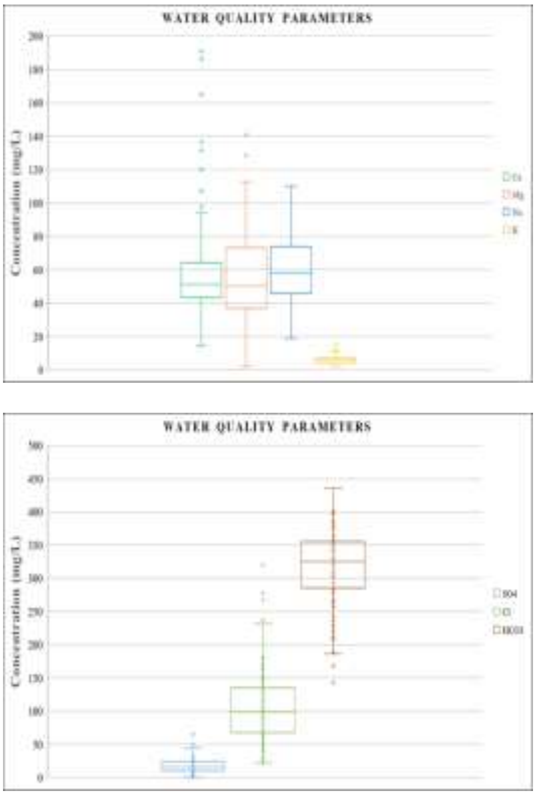

Fig. 12: Box-and-whisker plot of water quality parameters in pre-monsoon season

4 Conclusions

The main aim of this study was to assess the groundwater quality in and around (5 km) the Peenya industrial area/estate in Bengaluru City, India. Various physical and chemical characteristics were assessed in groundwater samples collected during and after the monsoon season. The quality of groundwater varied greatly in comparison to drinking water regulations. The predominant cations in groundwater are Ca^{2+} and Mg^{2+} for both seasons. The prevalence of anion in groundwater for both seasons is due to Cl^{-} and NO_3 respectively. The groundwater which is contaminated by untreated industrial waste sewage has penetrated through the soil and contaminated the groundwater of the study region. WQI values for the 116 Groundwater samples both in and around the Peenya industrial area ranged from 39.103 to 224.168 and 39.641 to 192.387 and pre-/post-monsoon season. out of which 30 Groundwater samples inside the Peenya industrial area ranged from 70.571 to 196.017, with 83 % and 93% poor water in pre-/post-monsoon season. Poor to very poor categories of WQI (water quality index) were observed inside the industrial areas, where the contamination level is higher. Based on the results of this study, policymakers can reduce the amount of work involved in initiating water quality management activities for groundwater remediation in the northeastern regions of the study area. It is also recommended that groundwater quality be periodically monitored within the industrial areas and in the western region outside the Peenya industrial area to stop further deterioration of the water quality in the study area. The type of water that predominates in the examined area is Ca-Mg-HCO3 type during both pre- and post-monsoon seasons of the year 2021, based on hadrochemical facies. Continuous monitoring of water quality in this area will help in understanding the progressive improvement in groundwater quality during the process of restoration to improve the groundwater quality.

Acknowledgement:
The First author is thankful to the AICTE, Government of India, New Delhi for sponsoring the opportunity to carry out this study. The author would also like to acknowledge Dr. Ramakrishnaiah C. R, Professor, Civil Engineering Department, BMS College of Engineering, Bengaluru for his study assistance.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Pavithra N carried out Conceptualisation, investigation, data curation, methodology, writing – original draft, visualization, and validation.
- Dr. Ramakrishnaiah C R was responsible for Supervision, conceptualization, reviewing, and editing.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This work is supported by institutional scholarship from AICTE, Government of India, New Delhi.

Conflict of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.