ASSESSMENT OF SURFACE AND GROUNDWATER QUALITY IN TIKAMGARH CITY, MADHYA PRADESH, INDIA

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ABSTRACT

Surface water and groundwater are primary resources for communities living in arid and semi-arid regions. The expansion of industrial and agricultural practices has raised pressure on natural resources. Water quality assessment provides valuable information about potential of resources for intended uses. The correlation study was carried out on the physicochemical parameters of surface water and groundwater in the Tikamgarh city. The physicochemical parameters, such as pH, total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), total alkalinity (TA), sulphate (SO_4^{2-}), fluoride (F^-), iron (Fe), nitrate (NO_3^-), chloride (Cl^-) and turbidity were analysed to determine correlation between parameters. The grab sampling technique was adopted to collect water samples from selected dug wells and reservoirs. The results of physicochemical parameters were fitted in the correlation coefficient equation to predict probable values of different parameters for selected locations. Results of the correlation study showed that calcium and TH are strongly correlated, followed by TH with chloride. However, Ca^{2+}, TH, Cl^-, TA, TDS, SO_4^{2-}, and iron show a high correlation. The findings show that water quality can be managed by controlling TH and TDS concentrations through conventional and non-conventional treatment methods.

Keywords: correlation, surface water and groundwater, Tikamgarh city, water quality

INTRODUCTION

Surface water and groundwater are key sources for community water supply needs. Groundwater is a common water source for rural areas and small towns, while rivers, ponds, and lakes are common sources for large cities [1, 2]. However, approximately 98 % of freshwater exists as groundwater at greater depths [2, 3]. The depth of groundwater makes pumping very expensive, preventing the overall development and use of readily available groundwater resources. Due to overuse and contamination of water, fresh water has gradually become restricted only to greater depths [4]. Ponds and small lakes make

up most of the continental water area. The quality of surface and subterranean waters has declined due to population growth and the discharge of untreated wastewater in open and unlined drains [5, 6]. The frequent occurrence of extreme weather events that cause either floods or droughts also contributes to the reduction of the quantity and quality of groundwater resources [7]. The daily consumption of groundwater for domestic, agricultural, and industrial purposes has increased significantly with exponential growth of the population. Waste from the household enters groundwater and surface water by seepage from drains, small and big ditches and pits, also contributing to the degradation of water quality [8]. In addition, natural rocks and minerals also threaten the quality and purity of both water sources. The point and non-point sources cause the mixing and interaction of several chemical constituents and nutrients, which requires the identification of critical parameters affecting the water quality [9]. Several researchers have performed studies for the identification of the interaction of various chemical constituents in surface water and groundwater [10 - 15]. Jothivenkatachalam et al. [10] conducted a correlation analysis of drinking water quality in and around Perur Block of Coimbatore district, Tamil Nadu, India. In order to find correlation between the parameters, this study investigated physiochemical and biological parameters, such as pH, electrical conductivity, TDS, TH, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, total acidity, TA and dissolved oxygen (DO), etc. The results were compared to the standards of WHO, USPH and ICMR. A systematic correlation and regression study showed a significant linear relationship between water quality parameters. Gupta and Gupta [11] carried out the correlation and regression studies of drinking water resources, especially dug wells located in and around Kamadgiri Parikrima at Chitrakoot using temperature, turbidity, pH, TDS, electric conductivity (EC), calcium hardness, magnesium hardness, TH, Ca^{2+}, Mg^{2+}, sodium (Na^+), potassium (K^+), alkalinity, Cl^-, DO, biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The obtained values of the physicochemical

parameters were fitted in the regression equation to predict probable values of different physicochemical parameters of the selected water resources. The values of physiochemical parameters were compared with their prescribed standards. Seth et al. [12] performed a correlation study of the water quality parameters of the Himalayan rivers. This study investigated the water quality of critical rivers, i.e. Gola, Kosi, Ramganga, Saryu and Lohawati rivers located in the different districts of the Kumaun region of Uttarakhand Himalaya. River water samples collected in the pre-monsoon and post-monsoon seasons of 2011 and 2012 were analysed for various water quality characteristics to determine their correlation. Statistical analyses show positive correlation between most chemical parameters. Water quality assessment in terms of water quality index (WQI) of Kolong River, Assam, India, was carried out by Bora and Goswami [13]. The study was conducted to analyse the seasonal water quality status of the Kolong River in terms of the water quality index (WQI). The WQI values show very poor to unsuitable quality of water samples in almost all seven sampling sites along the Kolong River. It was found that the water quality deteriorated the most during the monsoon season, with an average WQI value of 122.47 compared to pre-monsoon and post-monsoon seasons, with average WQI values of 85.73 and 80.75, respectively. Kothari et al. [15] performed the correlation of various water quality parameters and water quality index of districts of Uttarakhand. The drinking water quality parameters including pH, TH, alkalinity, turbidity, Fe, Cl^-, F^-, TDS, SO_4^{2-}, NO_3^-, Ca^{2+}, Mg^{2+}, arsenic (As), conductivity, total coliform, faecal coliform and total residual chlorine were statistically analysed to calculate the correlation coefficient of different parameters with WQI and the study showed significant linear relationship and the high correlation coefficient among water quality parameters. Among these parameters, TDS has the highest correlation with conductivity, sulphate, and chloride ion concentration, whereas turbidity significantly correlates with the presence of nitrate in drinking water. All these studies have shown

that parameter correlation can lead to a critical understanding of different physiochemical constituents and interaction between parameters that affect the water quality.

The Bundelkhand region of Madhya Pradesh is a place known for drought, and the population mostly migrate from villages to cities for daily earnings for their living, which causes a lot of pressure on various water resources of the cities. Within Tikamgarh district, agriculture is the major source of income for field workers who earn a living on daily wages using groundwater for irrigation. Deteriorated water quality can cause various waterborne diseases in that area. In light of the above facts, this study was carried out to monitor and analyse the quality of groundwater and surface water in Tikamgarh city. Statistical analysis (correlation and regression) was also carried out. Correlation analysis determines the relationship between independent and dependent variables.

EXPERIMENTAL

Studied area

The Bundelkhand region of Madhya Pradesh consists of six districts, Sagar, Chhatarpur, Panna, Tikamgarh, Damoh and Datiya. It is bordered on the north by Niwari and Jhansi, on the west by Lalitpur districts of Uttar Pradesh, on the east by Chhatarpur district and on the south by Damoh and Sagar district of Madhya Pradesh. Tikamgarh is located in the northern part of Madhya Pradesh on the Bundelkhand Plateau between Jamuni, "a tributary of Betwa River", and the Dhasan River. The entire city falls under the Betwa sub-basin of the Ganga basin. Its geographic location is between 24°26' and 25°34' N latitudes and 78°26' and 79°21' E longitudes, as shown in Figure 1. The maximum length and width of the district are about 119 km and about 80 km, respectively. Thus, the total geographical area of the district is 5048 km^2.
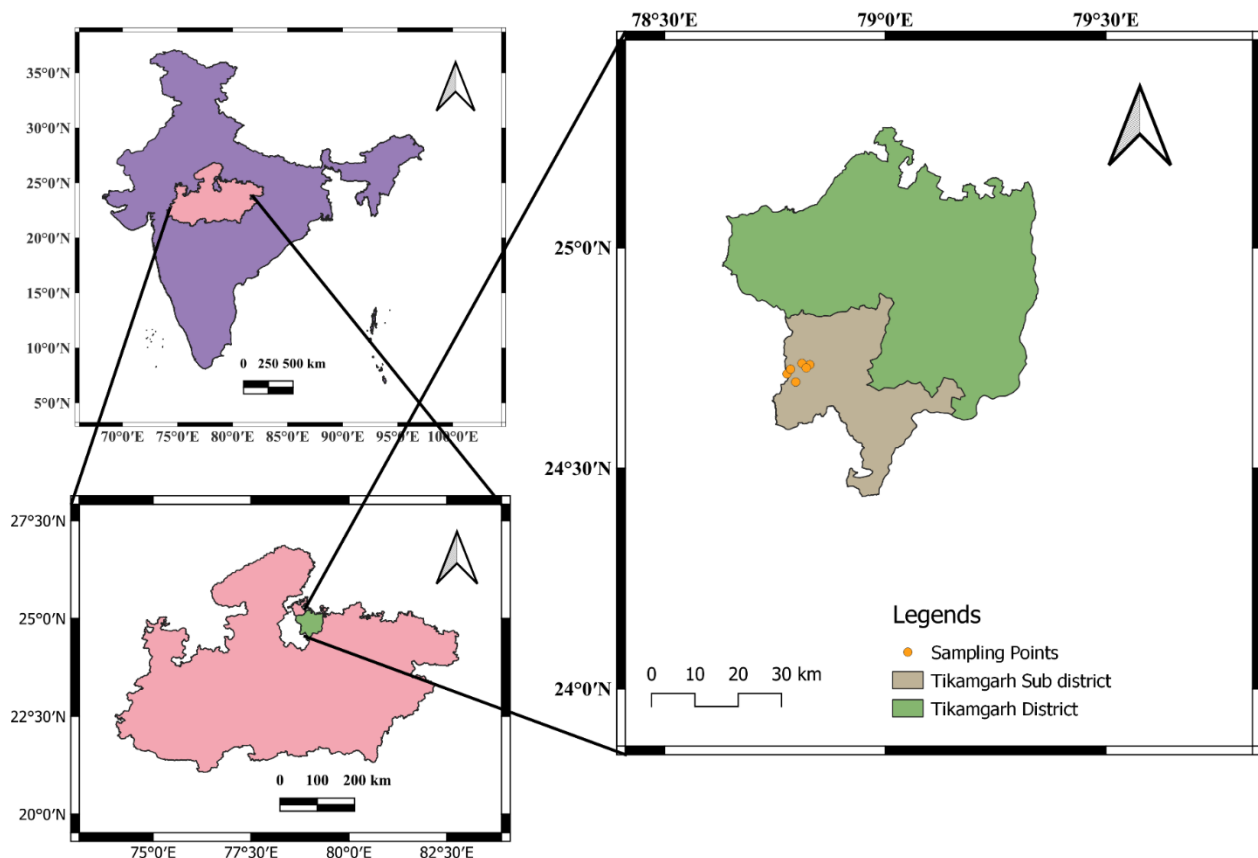

Figure 1. Studied area in Tikamgarh district

The central part of the study area consists of Bundelkhand granite rocks and soils characterised as black humus granitic and yellowish grey colour with kankar soils. The average annual rainfall in Tikamgarh district is 1057.1 mm. The groundwater in the area generally takes place under water table conditions. It is also known as part of Bundelkhand of Madhya Pradesh, famous for frequent droughts. This is the reason why the Chendala and Bundela dynasties developed several reservoirs in their period to meet the basic needs for water resources.

Methodology

Five surface and groundwater basins around Tikamgarh city are used for city water supply, i.e., Mahendra Sagar Pond, Kundeshwar Dam, Barighat Dam, Barighat filtered water and Maharajpura Well were selected for monitoring and physicochemical analysis to determine the correlation between independent (X) and dependent variables (Y). Mahendra Sagar Pond, Kundeshwar Dam and Barighat Dam represent the surface water sources and other two locations are source of groundwater, as shown in Table 1. The monitoring was carried out once a year in 2022. Two-litre water samples were collected at different locations to analyse water quality parameters. The physiochemical parameters that were examined are: turbidity, pH, TDS, TH, Ca^{2+}, Mg^{2+}, alkalinity, Cl^-, nitrate, fluoride, iron, and sulphate. Water samples were collected in pre-cleaned polypropylene bottles with necessary precautions according to APHA-AWWA-2017 [16]. Laboratory glassware and chemicals used in the study were of high quality and obtained from Schott Duran, Borosilicate and Revera and Qualigens/E-Merck/Hi-media/Loba. The TDS parameter was measured with a mobile pen-type TDS meter and TDS meter (EI, model 601) at the sampling point, while other parameters were analysed in the laboratory according to standard methods for testing water and wastewater [16]. Turbidity and pH were measured with a digital turbidity meter (EI, model 331) and pH meter (EI, model 101), respectively. TH, alkalinity, and chloride

were determined by the volumetric titration method. Total hardness was determined by EDTA titration method using ammonium buffer (NH_4Cl and NH_4OH) and Eriochrome Black-T indicator in water samples. The value of total hardness was calculated as $CaCO_3$ mg/l. Alkalinity was analysed by titration method using 0.02N H_2SO_4, phenolphthalein and methyl orange indicators. Cl^- was estimated by the $AgNO_3$ titration method using K_2CrO_4 as an indicator. The sulphate, fluoride, iron, and nitrate were measured using a visible spectrophotometer (Model - 168, Make - Systronics) in the range from 340 to 1100 nm and accuracy of ± 1 nm. The detailed locations of selected sampling points are shown in Table 1. The geographical position of the locations was determined with the help of the Global Positioning System (GPS). The analysis was carried out at Public Health Engineering (PHE) Department and Government Post Graduate College, Tikamgarh, Madhya Pradesh. The Government Post Graduate College is considered as the central point, and the distance of each sampling point from the central point is shown in Table 1. The data has been evaluated by means of the Karl Pearson correlation coefficient (R) using the following equation to determine the strength of relationship between two variables:

$$R = \frac{n\sum xy - \sum x \sum y}{\sqrt{n\sum x^2 - \left(\sum x\right)^2}\sqrt{n\sum y^2 - \left(\sum y\right)^2}} \quad (1)$$

where *n* is the number of selected stations, *x* and *y* are independent and dependent variables, respectively. The relationship between variables *x* and *y* was evaluated by a straight-line equation, i.e., y = mx + c, where m is slope and c is the intercept. If the value of the correlation coefficient is closer to +1 or -1, it indicates the probability of a linear relationship between independent and dependent variables *x* and *y*. The correlation coefficient was determined using Python programming, through Google Colab platform.

Table 1. Details of sampling locations from Government Post Graduate College, Tikamgarh, Madhya Pradesh

No.	Sample code	Location	Abbrev.	Latitude	Longitude	Source	Distance from the central point (km)
1	N-22-8/1	Mahendre Sagar Pond	MSP	24.7354	78.8291	Surface water	1
2	N-22-8/2	Barighat Dam	BD	24.7144	78.7772	Surface water	6.5
3	N-22-8/3	Kundeshwar Dham	KD	24.696	78.7971	Surface water	2.1
4	N-22-8/4	Barighat filtered water	BFW	24.7249	78.7853	Ground water	6.3
5	N-22-8/5	Maharajpur Well	MW	24.7383	78.8113	Ground water	3.5

RESULTS AND DISCUSSION

Statistical analysis

Surface water and groundwater samples were collected in Tikamgarh city. Five sampling locations were selected, of which three samples represent a surface source and two samples represent groundwater. Mahendre Sagar Pond, Barighat Dam and Kundeshwar Dham represent the surface water sources, where Barighat Dam represents the river location and other two locations are ponds. The Barighat filtered water and Maharajpur Well are groundwater sources. The statistical variation in water quality characteristics for all the locations are shown in Figure 2. The obtained results were also compared with their standards prescribed by BIS [17].
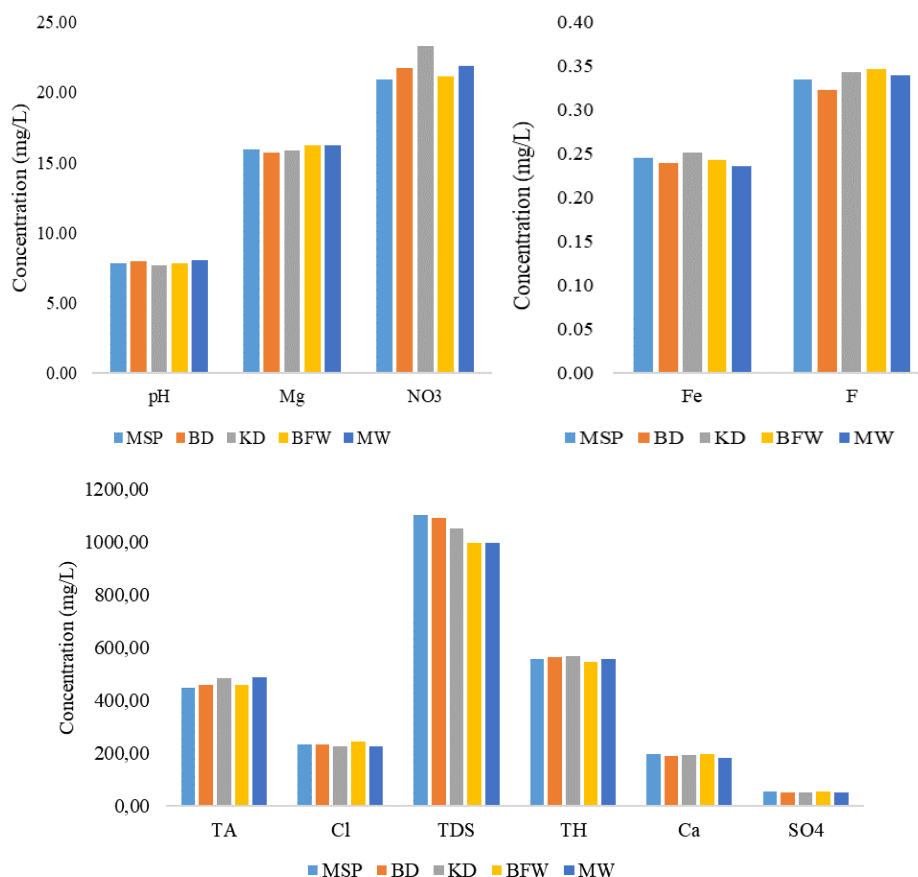

Figure 2. Water quality characteristics of different sampling locations

As shown in Figure 1, keeping in mind that all the sampling locations are within a radius of 6.5 km from central point i.e., Government Post Graduate College, Tikamgarh, Madhya Pradesh, low variation in concentration of parameter were observed between different locations. The pH in all locations is similar and varies within the permissible range of 6.5 to 8.5 (Table 2). According to BIS standard IS 10500:2012 [17], the acceptable limit of Mg^{2+} is 30 mg/L. In MW, the highest mean concentration of Mg^{2+} was found (16.18 mg/L). Maximum concentration was found in BFW (17.94 mg/L). In all samples, Mg^{2+} was within acceptable limits. According to standard, the acceptable limit of NO_3^- is 45 mg/L and all the samples were within that limit. The highest mean concentration of NO_3^- was found at KD and maximum concentration was also found at KD (27.55 mg/L). The acceptable limit of Fe and F^- is 0.3 mg/L and 1.0 mg/L, respectively, and both the parameters were within the acceptable limits. The highest mean concentration of Fe was found in KD (0.25 mg/L). Maximum concentration of Fe was also found in KD (0.32 mg/L), which is slightly above the limit. Maximum concentration of F^- was 0.41 mg/L and average concentration was 0.34 mg/L. The turbidity was measured in NTU and was less than 10 NTU in almost all sampling locations. The maximum turbidity was observed in MSP (10.05 NTU) and minimum turbidity was also found in MSP (1.41 NTU). In other locations, the maximum turbidity varied between 2 - 9 NTU.

The average concentration of chemical constituents was also within standard acceptable limits. In KD, the mean value of TA was 482.9 mg/L, while the maximum concentration of TA was 592.5 mg/L. The acceptable limit of Cl^- is 250 - 1000 mg/L and all the sample were within the acceptable limit. The maximum concentration of Cl^- was found in BD (351.8 mg/L), while the highest mean concentration was found in BFW (244.8 mg/L). The permissible limit for TDS is 2000 mg/L. All the samples were within the limit with maximum concentration of 1462.6 mg/L

in BD. The highest mean value of TDS was found in MSP. Similarly, TH, Ca^{2+} and SO_4^{2-} were also within the permissible limits. TH was above 600 mg/L in few samples, while the mean concentration remained below 600 mg/L. The maximum concentration of Ca^{2+} also rises above 200 mg/L, while the mean concentrations were below 198.1 mg/L. The SO_4^{2-} was within acceptable limits, as shown in Table 2. All the samples were within the permissible limits, except for a few parameters.

Correlation analysis

All parameters were correlated with each other to determine the significance of the correlation based on the level and direction of the correlation. The correlations, whether positive or negative, are considered significant if they are greater than ± 0.8, moderate if they are in the range $\pm 0.80 > C > \pm 0.40$ and non-significant if they are less than ± 0.40.

It was found that the chemical water quality parameters are highly correlated with each other (Table 3). Only Mg^{2+} shows a low correlation with almost all parameters. The maximum correlation of Mg^{2+} was with Cl^- (0.437), which is not significant enough to derive a relationship between the parameters. pH showed a moderate correlation with most parameters. The maximum correlation was with iron, followed by sulphate. At the same time, other parameters show a striking correlation with different parameters. TH had a correlation above 90 % with all parameters, except with Mg^{2+} and pH. Similarly, Ca^{2+}, TA, and Cl^- show exceptional correlation. A strong correlation of TH was found with Ca^{2+}, TA, Cl^-, Fe and SO_4^{2-}. At the same time, a strong correlation of TA with Cl^-, TH and Ca^{2+} was found. Fe and SO_4^{2-} also show a high correlation with most parameters, as shown in Table 3.

Table 2. Descriptive statistics of water quality parameters of different locations

Locations		pH	TH (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	TA (mg/L)	Cl$^-$ (mg/L)	NO$_3^-$ (mg/L)	TDS (mg/L)	Fe (mg/L)	SO$_4^{2-}$ (mg/L)	F$^-$ (mg/L)	Turbidity (NTU)
	BIS	6.5-8.5	200-600	75-200	30-100	200-600	250-1000	45	500-2000	0.3	200-400	1-1.5	1-5
Mahendre Sagar Pond	Mean	7.79	557.03	198.10	15.89	445.79	233.08	20.90	1100.08	0.24	54.46	0.33	4.61
	Minimum	7.51	436.42	179.27	14.43	351.33	198.62	19.08	730.91	0.15	50.01	0.28	1.41
	Maximum	8.09	636.94	221.52	17.01	576.34	303.18	22.61	1368.32	0.31	58.12	0.39	10.05
	Median	7.75	562.88	196.02	15.83	428.58	222.55	21.12	1154.78	0.26	54.62	0.33	3.89
	Standard deviation	0.21	59.38	13.72	0.74	76.32	35.15	1.33	216.81	0.05	2.40	0.03	2.83
Barighat Dam	Mean	7.93	562.55	190.85	15.67	457.10	234.09	21.75	1090.15	0.24	52.00	0.32	5.76
	Minimum	7.49	489.15	166.56	14.49	330.54	156.54	17.72	839.37	0.17	43.10	0.28	2.97
	Maximum	8.35	635.85	216.03	16.62	571.41	351.86	25.94	1462.69	0.28	57.58	0.36	9.32
	Median	7.90	570.01	188.21	15.86	453.52	225.72	21.87	1035.44	0.26	52.58	0.32	5.15
	Standard deviation	0.25	50.31	17.30	0.63	76.56	54.14	2.66	205.15	0.04	4.36	0.02	2.18
Kundeshwar Dham	Mean	7.69	566.35	192.16	15.84	482.99	227.15	23.27	1049.35	0.25	50.09	0.34	6.02
	Minimum	7.11	505.21	167.10	14.67	410.08	169.60	19.25	855.96	0.20	44.13	0.29	3.40
	Maximum	8.24	635.46	219.38	17.06	592.57	296.96	27.55	1216.28	0.32	54.93	0.39	9.08
	Median	7.73	567.89	187.73	16.01	483.31	232.19	23.04	1056.37	0.23	49.70	0.36	6.06
	Standard deviation	0.35	38.17	17.30	0.71	57.32	44.16	2.38	116.31	0.05	3.20	0.04	1.70
Barighat filtered water	Mean	7.80	547.25	195.41	16.25	459.89	244.85	21.14	994.71	0.24	53.78	0.35	6.91
	Minimum	7.20	452.33	160.94	14.68	401.09	164.86	17.31	743.80	0.16	49.14	0.31	2.78
	Maximum	8.21	638.52	228.84	17.94	516.32	334.37	23.22	1158.66	0.30	62.02	0.41	9.00
	Median	7.77	529.08	194.19	16.25	459.77	251.20	21.22	1008.32	0.25	52.27	0.34	7.33
	Standard deviation	0.28	54.87	23.28	0.99	40.09	62.25	1.62	133.93	0.04	4.19	0.03	1.82
Maharajpur Well	Mean	8.05	557.33	184.07	16.18	485.72	226.19	21.89	997.18	0.24	52.79	0.34	6.13
	Minimum	7.68	511.58	159.35	14.34	329.75	172.33	18.60	806.74	0.20	48.50	0.25	3.04
	Maximum	8.49	597.57	200.82	17.32	546.55	288.67	24.37	1282.43	0.29	58.10	0.40	9.19
	Median	7.97	569.28	188.17	16.69	499.38	229.81	22.05	978.98	0.22	53.06	0.35	6.55
	Standard deviation	0.28	31.96	13.59	1.07	67.15	42.39	1.90	141.14	0.03	3.25	0.05	2.25

Table 3. Correlation matrix of water quality parameters

	pH	TH	Ca^{2+}	Mg^{2+}	TA	Cl$^-$	NO$_3^-$	TDS	Fe	SO$_4^{2-}$	F$^-$	Turbidity
pH	1											
TH	0.658	1										
Ca^{2+}	0.669	0.998	1									
Mg^{2+}	0.057	0.339	0.274	1								
TA	0.495	0.979	0.977	0.331	1							
Cl$^-$	0.563	0.989	0.979	0.437	0.987	1						
NO$_3^-$	0.519	0.943	0.937	0.374	0.944	0.961	1					
TDS	0.521	0.901	0.907	0.197	0.914	0.877	0.738	1				
Fe	0.729	0.961	0.976	0.082	0.926	0.919	0.904	0.859	1			
SO$_4^{2-}$	0.673	0.964	0.974	0.160	0.945	0.927	0.838	0.966	0.959	1		
F$^-$	0.481	0.92	0.935	0.072	0.945	0.911	0.938	0.813	0.947	0.893	1	
Turbidity	0.596	0.854	0.887	-0.191	0.852	0.799	0.804	0.814	0.952	0.902	0.945	1

A high correlation between the TH and SO_4^{2-} indicates the presence of permanent hardness, while a high correlation between TA and Ca^{2+} suggest the presence of temporary hardness in groundwater. A high concentration of sulphate generated from mineralogical depositions and nitrate was observed as coming from anthropogenic sources. A high correlation of nitrates and sulphates indicates the anthropogenic pollution generated by wastewater discharge causing microbial contamination of groundwater. A high load of chlorides indicates contamination of groundwater with domestic wastewater and leakage of effluents from septic tank close to aquifers. The analysis of data collected from surface and sub-surface sources shows that there is no significant difference in the water quality characteristics of both sources [9] All the sampling locations are geographically distributed within a radius of 6.5 km and do not show any geographic variation; therefore, there are no significant fluctuation in both data source. Only a few exceptional cases were observed that showed a concentration of parameters above the acceptable values, but average concentration was within the permissible limits. The correlation analysis suggested that most of the parameters are highly correlated with each other except for Mg, as shown in Figure 3. High correlation and lower values of parameters indicate that there are no point or non-point sources that discharge wastewater into the surface waters (river or pond), and groundwater sources also do not receive any impurities by percolation.
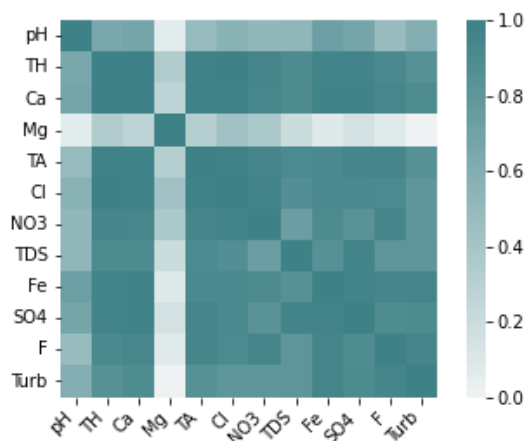

Figure 3. Correlation matrix of water quality parameters

CONCLUSION

A correlation study was performed to determine the relationship between different water quality parameters that affect the quality of surface water and groundwater. The variation of surface water quality parameters was compared with groundwater quality in order to assess the flow in the water resource and factors affecting the variation of the concentration of different parameters. The results of the correlation study showed that calcium and TH are strongly correlated, followed by TH with Cl⁻. Ca^{2+}, TH, Cl⁻, TA, TDS, SO_4^{2-} and iron shows a high correlation. The variation between surface and groundwater sources were not significant, indicating that no major point or non-point source joined the surface or sub-surface resources. The results of the correlation study suggest that water quality can be managed by controlling TH and TDS concentrations through conventional and non-conventional removal processes before processing for agricultural and domestic consumption.

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