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An Assessment of Groundwater Quality of Varanasi District using Water Quality Index and Multivariate Statistical Techniques

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Abstract

Water is one of the most indispensable resources and is the elixir of life. Modern civilization, industrialization, urbanization and increasing populations have led to rapid degradation of groundwater quality. It is estimated that approximately one-third of the world's population use groundwater for drinking. Those around Varanasi depend totally on groundwater resources. Heavy and constant groundwater use, without restriction, is lowering both the water table and water quality. Any type of contamination present in groundwater, will leads to several health related problems. Owing to this pressure on resources, the water quality around Varanasi, in the middle Ganga plain, was studied. Twelve water quality parameters (iron, nitrate, fluoride, chloride, pH, TDS, alkalinity, turbidity, sulfate, calcium, magnesium, and hardness) were investigated relating to 2015/16 for eight blocks of Varanasi district. Groundwater quality was calculated by using correlation, principle component analysis (PCA) and water quality index (WQI). In general, good water quality was found in all but one block Kashi Vidya Peeth has poor water quality.

Introduction

Water is indispensable for life and groundwater is a major source of drinking water. Modern civilization, industrialization, urbanization and increasing populations have led to rapid degradation of groundwater quality. It is believed that groundwater must be free from chemical contamination and microorganisms (Goel, 2000). Groundwater is an important natural resource, and very large volumes are pumped each day for industrial, agricultural, and commercial use (Sirajudeen and Vahith, 2014). It is the drinking water source for about half of India's population, including most residents in rural areas.

Information on groundwater quality and quantity is important because of the nation's increasing population and dependence on it. It is estimated that abstraction has increased about five-fold since the mid-1960s (Sirajudeen and Vahith, 2014).

The importance of groundwater in India is shown by the fact that about 50% of Indian irrigation depends on it (Central Water Commission, 2000). Excess groundwater abstraction is to blame for the 61% decline in groundwater levels in wells in India between 2007 and 2017, according to the CGWB (2000) of the Ministry of Water Resources. Long-term conservation, and prudent development and management of groundwater are critical for preserving and protecting it. Pollution by agricultural fertilizers and pesticides, often widely dispersed, is a threat to groundwater ecosystems. Pollution from industrial effluents and municipal waste is another major concern in cities and industrial clusters in India. Continuous groundwater monitoring is required to minimize and control pollution. It is estimated that approximately one-third of the world's population use groundwater for drinking (Nickson *et al*., 2005). People in the Varanasi area depend totally on groundwater. Contamination could lead to severe health effects. Many diseases are carried by contaminated water. Because of these potential issues, the study was focused on eight block of Varanasi district. Groundwater samples were analyzed for various physico-chemical parameters including iron (Fe) and fluoride (F), both of which can affect human beings, animals and plants.

Varanasi abstracts about 280 mega liters of water from groundwater sources and the Ganga River. The water table beneath Varanasi has fallen from about 14 to 16 m to between 20 and 22 m below ground level in the urban area since about 2010. At the same time, groundwater quality has also been deteriorated. The aim of this study was to evaluate the significance of water quality statistically and through calculation of WQI (Water Quality Index). Multivariate statistical analysis techniques such as principal component analysis (PCA) were applied to characterize and evaluate groundwater quality, by natural and anthropogenic factors (Helena *et al*., 2000; Shrestha & Kazama, 2007; Singh *et al*., 2005). These techniques effectively compress the data and reveal inter-parameter correlations.

Data Collection

Data of year 2015/16 were collected from the Indian Ministry of Drinking Water and Sanitation, relating to eight blocks in the Varanasi district – Arajiline (112 samples), Baragaon (76), Chiraigaon (133), Cholapur (42), Harhua (171), Kashi Vidya Peeth (155), Sewapuri (83), and Pindara (8). Data analysis was done using MS-Excel 2013 and IBM SPSS statistics 20.

Study Area

Varanasi district lies in the middle Ganga plain in eastern part of state Uttar Pradesh (India), between about 25°10' and 25°37' N, and 82°39' and 83°10' E (Rai and Mohan, 2014) (Figure 1). The district is underlain by quaternary alluvial sediments of Pleistocene and more recent age (Raju *et al*., 2011). Varanasi's geological settings and aquifers have dominated by interlayered sands and clays (Shukla and Raju, 2008).

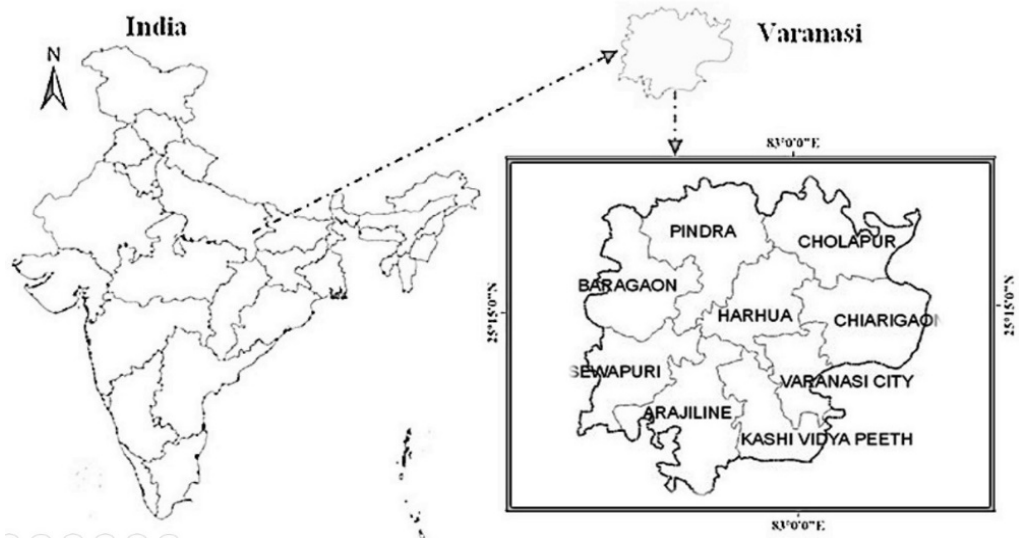

Figure 1 The study area and the eight blocks of Varanasi district (Uttar Pradesh)

Results and Discussion

The parameters selected for study were iron, nitrate, fluoride, chloride, pH, total dissolved solids (TDS), alkalinity, turbidity, sulfate, calcium, magnesium, and hardness – see Table 1.1-1.4. The analytical results for most of the parameters for water samples were within the permissible limits (BIS, 1991).

pH: The groundwater pH ranged from 6.7 to 8.67 (Table 1.1-1.4) i.e., it is neutral to alkaline. The permissible range is from 6.5 to 8.5 (BIS, 1991) and the results from all but one sampling point, in Kashi Vidya Peeth, where it was 8.67 were acceptable.

TDS: This comprises the sum of the masses of all dissolved solids in solution, whether organic or inorganic. The TDS content of the groundwater samples ranged from 145 to 2,900 mg/l, the maximum being found in three sampling points in Kashi Vidya Peeth.

Magnesium: The interactions of water with rocks and soils can lead to ion exchange, affecting the magnesium concentration in groundwater. The Mg^{2+} concentration in the samples ranged from 3 to 337 mg/l, the maximum values being found in three sampling stations in Kashi Vidya Peeth and one in Sewapuri.

Calcium: The standard value of calcium in potable water ranged from 75-200 mg/l. The calcium concentration in the samples ranged from 6 to 218 mg/l, the maximum value being reported from one sampling station in Kashi Vidya Peeth.

Table 1.1Groundwater analytical data from the Varanasi area (Arajiline and *Baragaon)*

Parameter	Permissible range (BIS, 1991)	*Arajiline*		*Baragaon*	
		(Mean±SD)	Range	(Mean±SD)	Range
Iron [mg/l]	0.3-1	(0.1±0.1)	(0.01-0.6)	(0.2±0.6)	(0.02-5)
Nitrate [mg-NO_3/l]	45-100	(5.8±3.8)	(1-16)	(6.3±4.6)	(0.5-20)
Fluoride [mg/l]	1-1.5	(0.3±0.3)	(0.01-1.43)	(1.1±6.3)	(0.01-56)
Chloride [mg/l]	250-1000	(56.9±22.2)	(28-192)	(55.3±10)	(32-96)
pH	6.5-8.5	(7.9±0.3)	(7-8.2)	(7.7±0.3)	(7-8.2)
TDS [mg/l]	500-2000	(427±86.1)	(230-700)	(448.1±56)	(299-618)
Alkalinity [mg/l as $CaCO_3$]	120-600	(313.5±69.8)	(180-546)	(292.3±53.6)	(192-396)
Turbidity [NTU]	5.0-10	(2.7±1.1)	(0.72-5)	(3.5±7.8)	(0.8-68)
Sulfate [mg/l]	200-400	(7.1±5.5)	(1-25)	(7.6±6)	(1-25)
Calcium [mg/l]	75-200	(63.4±20.8)	(18-124)	(60.4±12.6)	(30-90)
Magnesium [mg/l]	30-100	(39.5±8.9)	(17-56)	(40.1±8.2)	(22-58)
Hardness [as $CaCO_3$ mg/l]	300-600	318.1±70.9)	(144-504)	(308±69.9)	(29-506)

Table 1.2 Groundwater analytical data from the Varanasi area (*Chiraigaon* and *Cholapur)*

Parameter	Permissible range (BIS, 1991)	*Chiraigaon*		*Cholapur*	
		(Mean±SD)	Range	(Mean±SD)	Range
Iron [mg/l]	0.3-1	(0.1±0.4)	(0.01-5)	(0.1±0.0)	(0.02-0.21)
Nitrate [mg-NO_3/l]	45-100	(9±8.9)	(0.38-44.9)	(4.6±5.2)	(2-30)
Fluoride [mg/l]	1-1.5	(0.8±0.6)	(0.11-4.9)	(0.4±0.4)	(0.02-1.3)
Chloride [mg/l]	250-1000	(79.7±48.7)	(24-304)	(73.8±66.5)	(24-336)
pH	6.5-8.5	(7.8±0.4)	(6.7-8.5)	(7.9±0.1)	(7.4-8.1)
TDS [mg/l]	500-2000	(413.7±124.3)	(230-838)	(492.8±153.1)	(260-1036)
Alkalinity [mg/l as $CaCO_3$]	120-600	(286.2±79.2)	(29-552)	(331.9±55)	(184-432)
Turbidity [NTU]	5.0-10	(7±24.6)	(0.3-200)	(2.5±0.6)	(1-3.9)
Sulfate [mg/l]	200-400	(11.5±10.8)	(1-68)	(10.7±20.5)	(1-86)
Calcium [mg/l]	75-200	(42.2±15.3)	(13-88)	(66.1±15.6)	(32-118)
Magnesium [mg/l]	30-100	(43.4±19.2)	(3-100)	(42.1±8.8)	(23-65)
Hardness [as $CaCO_3$ mg/l]	300-600	(282.3±76.5)	(112-524)	(335.8±64.4)	(176-448)

Table 1.3 Groundwater analytical data from the Varanasi area (*Harhua* and *Kashi Vidya Peeth)*

Parameter	Permissible range (BIS, 1991)	*Harhua*		*Kashi Vidya Peeth*	
		(Mean±SD)	Range	(Mean±SD)	Range
Iron [mg/l]	0.3-1	(0.1±0.2)	(0.01-2.2)	(0.2±0.6)	(0.01-5.1)
Nitrate [mg-NO_3/l]	45-100	(11.2±12.1)	(0.6-76)	(17.2±25.4)	(0.01-220)
Fluoride [mg/l]	1-1.5	(1.0±5.1)	(0.01-56)	(0.9±0.5)	(0.02-2.49)
Chloride [mg/l]	250-1000	(57±29.5)	(16-212)	(102.6±90.3)	(24-544)
pH	6.5-8.5	(7.9±0.3)	(6.8-8.5)	(8.1-0.3)	(7.2-8.65)
TDS [mg/l]	500-2000	(341.6±120.4)	(145-860)	(571.2-367.4)	(215-2900)
Alkalinity [mg/l as $CaCO_3$]	120-600	(241.4±69.5)	(120-472)	(308.6-89.7)	(116-536)
Turbidity [NTU]	5.0-10	(4.6±14.4)	(0.25-178)	(10.2-52.9)	(0.04-523)
Sulfate [mg/l]	200-400	(8.8±10.1)	(1-88)	(17.8-13.7)	(0.51-72)
Calcium [mg/l]	75-200	(31.8±16.5)	(6-82)	(50.5-28.7)	(10-218)
Magnesium [mg/l]	30-100	(37.9±14.9)	(3-79)	(52.9-29.5)	(6-205)
Hardness [as $CaCO_3$ mg/l]	300-600	(230.6±69.3)	(80-504)	(343.3-166.5)	(64-1240)

Table 1.4 Groundwater analytical data from the Varanasi area (*Sewapuri* and *Pindara)*

Parameter	Permissible range (BIS, 1991)	*Sewapuri*		*Pindara*	
		(Mean±SD)	Range	(Mean±SD)	Range
Iron [mg/l]	0.3-1	(0.1±0.1)	(0.01-0.3)	(0.04±0.06)	(0.01-0.17)
Nitrate [mg-NO_3/l]	45-100	(6.6±7.7)	(1-30.9)	(5.8±2.8)	(1.2-10)
Fluoride [mg/l]	1-1.5	(0.5±0.5)	(0.01-1.3)	(0.4±0.2)	(0.21-0.71)
Chloride [mg/l]	250-1000	(77.9±47.6)	(36-340)	(95.8±28.5)	(64-136)
pH	6.5-8.5	(8±0.2)	(7.5-8.4)	(8±0.1)	(7.9-8.2)
TDS [mg/l]	500-2000	(400±139.1)	(251-879)	(396.1±44.7)	(320-435)
Alkalinity [mg/l as $CaCO_3$]	120-600	(249.8±69.5)	(128-404)	(259.3±38.4)	(196-310)
Turbidity [NTU]	5.0-10	(2.5±0.9)	(1.2-4.9)	(3.7±1.2)	(1.2-4.9)
Sulfate [mg/l]	200-400	(10.2±10.5)	(1-68)	(22.9±5.5)	(19-35)
Calcium [mg/l]	75-200	(54±16.2)	(27-104)	(47.6±11.1)	(36-72)
Magnesium [mg/l]	30-100	(36.2±35.2)	(9-337)	(35.3±6.8)	(25-44)
Hardness [as $CaCO_3$ mg/l]	300-600	(263.2±78.4)	(22-424)	(260.8±29.4)	(220-304)

Hardness: The permissible range of hardness in potable water is from 300 to 600 as $CaCO_3$ mg/l. The hardness in the samples collected ranged from 22 to 1,240 as $CaCO_3$ mg/l, with the maximum occurring in samples from four stations in Kashi Vidya Peeth.

Alkalinity: The permissible concentration range for alkalinity in potable water is from 120 to 600 mg/l as $CaCO_3$. The concentration the samples ranged from 29 to 552 mg/l as $CaCO_3$; all the samples from eight blocks of Varanasi were found within the standard.

Turbidity: The maximum acceptable value of turbidity is 5 to 10 NTU. The samples reported between 0.04 and 523 NTU, with high levels in samples from six stations in Chiraigaon, four in Harhua, and three in Kashi Vidya Peeth.

Sulfate: All samples reported within the acceptable range for sulfate concentration, which is from 200 to 400 mg/l. The range found was from 0.51 to 88 mg/l.

Nitrate: The nitrate concentrations in the samples ranged from 0.01 to 220 mg-NO_3/l, with the highest levels at one sampling station in Harhua and two in Kashi Vidya Peeth.

Chloride: The standard value of chloride is 250-1000 mg/l. The concentration of chloride in groundwater samples ranged from 16-544 mg/l. All the samples of Varanasi district were within the permissible limit.

Iron: The standard value of iron ranged from 0.3-1 mg/l. The concentration of iron in groundwater samples ranged from 0.01-5.1 mg/l; maximum concentration was found in two districts – Harhua (two sampling stations) and Kashi Vidya Peeth (three).

Fluoride: The standard value of fluoride ranged from 1-1.5 mg/l. The concentration of fluoride in groundwater samples ranged from 0.01-56 mg/l; maximum concentration of fluoride was found at four sampling station of Chiraigaon; three sampling point of Harhua block; and eleven sampling station of Kashi Vidya Peeth.

Water Quality Index (WQI):

Evaluation of groundwater quality around Varanasi was done using the Water Quality Index (WQI)**,** which is a representation of the interaction between different parameters. The Indian drinking water standard (BIS, 1991) was used to calculate WQI. All 12 parameters determined – iron, nitrate, fluoride, chloride, pH, TDS, alkalinity, turbidity, sulfate, calcium, magnesium, and hardness – were used in the calculation and different parameters were weighted (wi) according to their relative importance in water quality in relation to drinking (Table 2).

The relative weight (Wi) of each parameter was calculated using equation 1:

$$Wi = {wi}/{\sum_{i=1}^{n} wi} \quad (1)$$

Where Wi is the relative weight, wi the weight of the parameter, and n the number of parameters.

The Wi for the various parameters are shown in Table 2.
The quality rating scale (qi) for each parameter was calculated by dividing its actual concentration of different water sample by its respective standard (BIS, 1991), and the result was multiplied by 100 – see Equation 2:

$$qi = \frac{Ci}{Si} * 100 \quad (2)$$

Where qi is the quality rating, Ci the concentration of the parameter in each sample (mg/L), and, Si the maximum permissible drinking water concentration for the parameter (mg/L or as appropriate) (BIS, 1991).
To calculate WQI, the sub-index (SI) is determined for each parameter using Equation 3:

$$SI_i = Wi * q \quad (3)$$

The WQI was calculated using Equation 4:

$$WQI = \Sigma SI_{i-n} \quad (4)$$

Where $SI_i$is the sub-index of the i^{th} parameter; Wi the relative weight of the i^{th} parameter; qi the quality rating based on the concentration of the i^{th} parameter, and n the number of parameters.

According to Batabyal and Chakraborty, 2015; there are five categories of WQI value: excellent water (WQI < 50); good water (50 to 100); poor water (100 to 200); very poor water (200 to 300); and water unsuitable for drinking (> 300). The WQIs for this study are presented in Figure 2 and the WQI range was from 66.92 to 105.01. Good quality water was found in general in Arajiline (WQI=71.88), Baragaon (82.55), Chiraigaon (83.45), Cholapur (75.89), Harhua (72.98), Sewapuri (66.92), and Pindara (67.43). It was relatively poor in Kashi Vidya Peeth (105.01). However, this was the first use of WQI-based assessment in the Varanasi area. WQI has been used for groundwater quality assessment in other parts of India, including Bardhaman, West Bengal (Batabyal and Chakraborty, 2015), Malda, West Bengal (Chakraborty *et al*., 2007), and Ballia, Uttar Pradesh (Krishan *et al*., 2016) where GIS was also used.

Statistical analysis by sample collection block wise

Correlation

Arajiline: A very strong correlation between calcium and hardness (0.9), strong correlation between hardness and TDS (0.8) was observed. Good correlation between

alkalinity. and calcium, magnesium and hardness (0.6, 0.5, 0.7), calcium and TDS (0.7), magnesium and hardness(0.7), Magnesium and TDS(0.6), alkalinity and TDS(0.6), pH and alkalinity(0.5), chloride and TDS(0.6), fluoride and iron(0.5), fluoride and nitrate(0.5) so, we can say that calcium and magnesium are the main reason of causing hardness in the water and these calcium and magnesium are the main constituent of TDS. Hardness and fluoride, calcium and fluoride, are negatively correlated thus indicating that fluoride does not govern the hardness of water and the calcium and fluoride have different source of origin.

Baragaon: Good correlation between alkalinity and calcium (0.6), alkalinity and magnesium (0.7), alkalinity and hardness (0.7), magnesium and hardness (0.7), calcium and hardness (0.5).

Table 2: Relative parameter weights

Parameters[a]	**Standard value**[b] **(Si)**	**Weight (wi)**	**Relative weight (Wi)**
Iron [mg/l]	0.3-1	4	0.0952
Nitrate [mg-NO_3/l]	45-100	5	0.1190
Fluoride [mg/l]	1-1.5	4	0.0952
Chloride [mg/l]	250-1000	3	0.0714
pH	6.5-8.5	4	0.0952
TDS [mg/l]	500-2000	4	0.0952
Alkalinity [mg/l as $CaCO_3$]	120-600	4	0.0952
Turbidity[NTU]	5-10	4	0.0952
Sulfate [mg/l]	200-400	4	0.0952
Calcium [mg/l]	75-200	2	0.0476
Magnesium [mg/l]	30-100	2	0.0476
Hardness [as $CaCO_3$ mg/l]	300-600	2	0.0476
		Σwi=42	ΣWi=1.0000
a. chemical parameters in mg/L or as otherwise appropriate.			
b. lower value indicates desirable limit, higher value the permissible limit in the absence of an alternative source (BIS, 1991).			

Chiraigaon: Strong correlation was found between hardness and TDS (0.8), hardness and magnesium (0.8). Good correlation was found between TDS and chloride (0.7), alkalinity and fluoride (0.6), sulfate and TDS (0.6), magnesium and TDS (0.6), sulfate and chloride (0.5), hardness and chloride (0.5), hardness and sulfate (0.5).

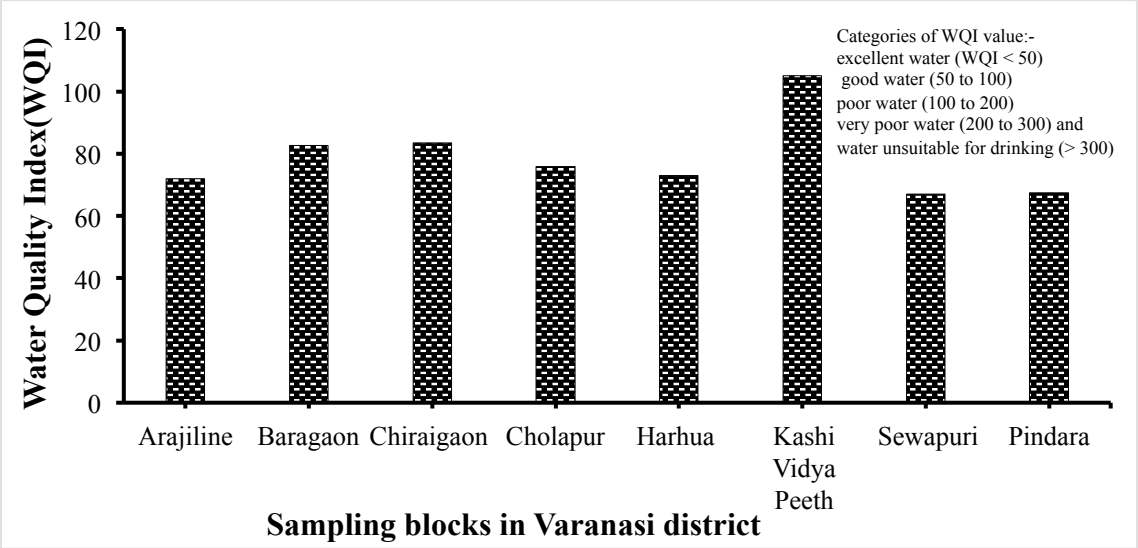

Figure 2 WQI, in eight blocks of Varanasi district, Uttar Pradesh.

Cholapur: Very strong correlation was found between chloride and TDS (0.9), TDS and sulfate (0.9), hardness and calcium (0.9), alkalinity with calcium, and hardness (0.9, 0.9). Strong correlation between hardness with magnesium (0.8), alkalinity and magnesium (0.8). Good correlation between sulfate and nitrate (0.7), TDS and calcium (0.7), TDS and hardness (0.6), calcium and magnesium (0.5), chloride and nitrate (0.5), calcium and chloride (0.5), TDS and alkalinity (0.5).

Harhua: Very strong correlation was found between TDS and hardness (0.9), good correlation was observed between TDS with alkalinity, sulfate, and magnesium (0.6, 0.6, and 0.6), alkalinity and hardness (0.5), and hardness with calcium and magnesium (0.5, 0.7).

Kashi Vidya Peeth: Very strong correlation was found between chloride and TDS (0.9), TDS and hardness (0.9), magnesium and hardness (0.9), Strong correlation between magnesium and TDS (0.8), hardness and chloride (0.8). Good correlation between TDS and nitrate (0.7), chloride with sulfate, magnesium (0.7, 0.7), TDS and sulfate (0.7), calcium and hardness (0.7), chloride and nitrate (0.6), nitrate with calcium, magnesium and hardness (0.5, 0.5, and 0.6), calcium and TDS (0.6), chloride with calcium (0.5), TDS

and alkalinity (0.5), alkalinity with magnesium and hardness (0.5) and sulfate with magnesium and hardness (0.6).

Sewapuri: Very strong correlation was found between alkalinity and hardness (0.9), strong correlation between alkalinity with calcium (0.8), Calcium and hardness (0.8), TDS with alkalinity, calcium, and hardness (0.8) whereas good correlation was found between chloride and TDS (0.7).

Pindara: Very strong correlation was found between iron and sulfate (0.9), iron and nitrate (0.9), magnesium and chloride (0.9), strong correlation was seen been TDS with magnesium, hardness (0.8, 0.8), Good correlation was observed between TDS with chloride, alkalinity (0.7, 0.7), alkalinity and hardness (0.7), pH with turbidity, calcium (0.5, 0.6), alkalinity and iron (0.5), turbidity and nitrate (0.5), sulfate and fluoride (0.5), hardness with calcium and magnesium (0.5,

PCA

Statistical analyses such as PCA are used mostly when large datasets are available and there is a need to reduce the set without losing the original value in it (Iscen *et al*., 2008). In this PCA, PC with Eigenvalues >1 are not considered because they do not explain much variation. Prior to PCA the Kaiser–Meyer–Olkin (KMO) (Chen *et al*., 2018). The Varimax with Kaiser Normalization rotation method was used to extract rotated component matrices for the principal components.

Arajiline: PCA analysis was proceeded for Arajiline having KMO value 0.647 as shown in (table 3.1); PC (1) shows a positive loading of TDS (0.853), alkalinity (0.815), calcium (0.761), magnesium(0.717), hardness(0.923) having variance of 31.535%. PC (2) shows a positive loading of chloride (0.675), turbidity (0.745), sulfate (0.717) have variance of 16.508%. PC (3) shows a positive loading of iron (0.771), nitrate (0.680), fluoride (0.627), having variance of 15.939%. PC (4) shows a highly positive loading of pH (0.937) having variance of 9.691%.

PCA was not worthwhile for Baragaon or Chiraigaon because the KMO values were <0.6.

Cholapur: PCA analysis was carried on for Cholapur having KMO value 0.643 as shown in (table 3.2); PC (1) shows positive loading of chloride (0.523), TDS (0.773), alkalinity (0.926), calcium (0.877), magnesium (0.812), and hardness (0.957) with variance of 34.711%. PC (2) shows positive loading of nitrate (0.795), chloride (0.654), TDS (0.505), sulfate (0.907) with variance of 19.997%. PC (3) shows positive loading of iron (0.86) whereas negative loading of pH (-0.716) was also observed with variance of 14.653.

PC (4) shows positive loading of iron (0.676) and turbidity (0.849) with variance of 11.543%.

Harhua: PCA analysis was carried on for Harhua block having KMO value of 0.617 as shown in (table 3.3); all together four major components was formed they are PC(1) showing positive loading of TDS(0.864), alkalinity(0.734), magnesium(0.845), hardness(0.859) with variance of 26.360%. PC(2) shows positive loading of iron(0.878), and turbidity(0.899) with variance of 13.830%. PC(3) shows positive loading of nitrate(0.561), calcium(0.693) whereas negative loading of pH(-0.754) with variance of 13.673%. PC(4) shows positive loading of chloride(0.761) and sulfate(0.590) with variance of 11.682%.

Table 3.1 PCA of Arajiline, Varanasi

Rotated Component Matrix[a]				
	Component			
	1	2	3	4
Iron	.046	-.186	**.771**	.150
Nitrate	-.178	.360	**.680**	-.064
Fluoride	-.410	.177	**.627**	-.175
Chloride	.445	**.675**	.081	-.027
pH	.052	.083	.027	**.937**
TDS	**.853**	.431	-.158	-.099
Alkalinity	**.815**	-.199	-.055	.247
Turbidity	-.157	**.745**	-.198	.271
Sulfate	.146	**.717**	.286	-.093
Calcium	**.761**	.089	-.426	.133
Magnesium	**.717**	.096	.212	-.228
Hardness	**.923**	.111	-.283	.056
% of variance	31.535	16.508	15.939	9.691
a. Rotation converged in 9 iterations.				
KMO and Bartlett's Test				
KMO measure of sampling adequacy.				**.647**
Bartlett's Test of Sphericity	Approx. Chi-Square			650.697
	df			66
	Sig.			.000

Table 3.2 PCA of Cholapur, Varanasi

Rotated Component Matrix[a]				
	Component			
	1	2	3	4
Iron	-.247	.219	-.393	**.676**
Nitrate	.038	**.795**	.252	-.218
Fluoride	.056	.224	**.860**	-.084
Chloride	**.523**	**.654**	.198	.045
pH	-.021	-.196	**-.716**	.041
TDS	**.773**	**.505**	.055	-.052
Alkalinity	**.926**	.047	.135	-.028
Turbidity	.096	-.316	.055	**.849**
Sulfate	.124	**.907**	.156	.010
Calcium	**.877**	.125	.302	.216
Magnesium	**.812**	.038	-.330	-.310
Hardness	**.957**	.081	-.025	-.048
% of variance	34.711	19.997	14.653	11.543
a. Rotation converged in 5 iterations.				
KMO and Bartlett's Test				
KMO measure of Sampling Adequacy.				**.643**
Bartlett's Test of Sphericity	Approx. Chi-Square			259.703
	df			66
	Sig.			.000

Kashi Vidya Peeth : PCA analysis was carried on for Kashi Vidya Peeth block having KMO value of 0.723 as shown in (table 3.4); all together three major components was formed they are PC(1) having positive loading of nitrate (0.742), chloride (0.891), TDS (0.962), sulfate (0.778), calcium (0.721), magnesium (0.835), and hardness (0.944) with a variance of 44.189%. PC(2) shows positive loading of turbidity (0.795) as well as negative loading of pH (-0.847) was found with a variance of 14.026%. PC(3) shows positive loading of fluoride (0.736) and alkalinity (0.744) with a variance of 13.108%.

Table 3.3: PCA of Harhua, Varanasi

Rotated Component Matrix[a]				
	Component			
	1	2	3	4
Iron	-.050	**.878**	-.027	-.065
Nitrate	.227	.210	**.561**	.142
Fluoride	.276	.025	-.254	-.477
Chloride	.173	.045	-.105	**.761**
pH	.078	.084	**-.754**	.185
TDS	**.864**	-.059	.204	.325
Alkalinity	**.734**	.010	.076	.103
Turbidity	-.084	**.899**	.041	.051
Sulfate	.450	-.068	.130	**.590**
Calcium	.224	-.056	**.693**	.235
Magnesium	**.845**	-.070	-.116	-.100
Hardness	**.859**	-.094	.348	.068
% of variance	26.360	13.830	13.673	11.682
a. Rotation converged in 5 iterations.				

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**.617**
Bartlett's Test of Sphericity	Approx. Chi-Square	789.171
	df	66
	Sig.	.000

Table 3.4 PCA of Kashi Vidya Peeth, Varanasi

Rotated Component Matrix[a]			
	Component		
	1	2	3
Iron	.401	.375	-.426
Nitrate	**.742**	-.122	-.205
Fluoride	-.039	-.371	**.736**
Chloride	**.891**	.064	.045
pH	.128	**-.847**	.051
TDS	**.962**	.005	.075
Alkalinity	.376	.180	**.744**
Turbidity	.005	**.795**	-.074
Sulfate	**.778**	-.036	.237
Calcium	**.721**	.049	-.251
Magnesium	**.835**	-.033	.313
Hardness	**.944**	-.018	.146
% of variance	44.189	14.026	13.108
a. Rotation converged in 5 iterations.			

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**.723**
Bartlett's Test of Sphericity	Approx. Chi-Square	913.123
	df	66
	Sig.	.000

Sewapuri: PCA analysis was carried on for Sewapuri block having KMO value of 0.664 as shown in (table 3.5); all together five principal components were formed they are PC (1) having positive loading of chloride (0.517), TDS (0.849), alkalinity (0.909), calcium (0.913), hardness (0.914) with a variance of 31.038%. PC(2) have positive loading of chloride (0.701), and sulfate (0.841) whereas negative loading of fluoride (-0.74) was found with a variance of 17.290%. PC (3) shows positive loading of turbidity (0.815) and negative loading of iron (-0.680) with a variance of 12.639%. PC (4) shows positive loading of pH (0.893) and negative loading of nitrate (-0.671) with a variance of 10.992%. PC (5) shows positive loading of magnesium (0.951) with a variance of 10.295%.

Pindara: PCA was not proceeded because the KMO value was <0.6

Table 3.5: PCA of Sewapuri, Varanasi.

Rotated Component Matrix[a]					
	Component				
	1	2	3	4	5
Iron	.001	.428	**-.680**	-.028	-.045
Nitrate	-.237	.264	.480	**-.671**	-.092
Fluoride	.338	**-.574**	-.189	-.024	.329
Chloride	**.517**	**.701**	-.208	.031	-.157
pH	-.104	.108	.160	**.893**	-.117
TDS	**.849**	.457	-.116	.059	-.023
Alkalinity	**.909**	-.105	-.178	.180	.192
Turbidity	-.166	.207	**.815**	.011	.019
Sulfate	.114	**.841**	.056	-.051	.347
Calcium	**.913**	.100	-.023	-.163	.051
Magnesium	.130	.049	.051	-.064	**.951**
Hardness	**.914**	-.089	-.058	-.012	.118
% of variance	31.038	17.290	12.639	10.992	10.295
a. Rotation converged in 7 iterations.					

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**.664**
Bartlett's Test of Sphericity	Approx. Chi-Square	375.835
	df	66
	Sig.	.000

Conclusions

Varanasi district covers an area of 1576 km^2 and fall under the Vindhyan groups of rocks; ground water quality of Varanasi district was studied for different blocks and with the help of analyzed data of the water quality parameters. The water quality index of Varanasi district admits that overall good water quality good except in Kashi Vidya Peeth, which was having poor water quality. In the Kashi Vidya Peeth block of Varanasi district ground water quality was found tobe contaminated due to over exploitation and over extraction of groundwater as well as seepage of runoff from domestic, small-scale industries, agriculture fields as well as from some workshops. It is high time to preserve and protect this valuable ground source. For this, various measures have to be taken to control the contamination from different sources. These include proper treatment and disposal of the effluent, proper drainage for the domestic and agricultural waste etc.

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