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Assessment of groundwater quality for drinking purposes in Arajiline block of Varanasi district of Uttar Pradesh

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Abstract
Drinking water quality is mandatory for the annual analysis of a region as it gives us a wide range of information about the entire aquifer quality as well as crop productivity of a region. Arajiline block of Varanasi district is a major crop productive block in the central Gangetic plain zone. It was chosen as the study area since a significant part of the groundwater is used for drinking and agricultural purpose. The objective of the study was to bring out an integrated approach for the assessment of groundwater quality for drinking purposes. An integrated approach that included the concentration of major cations, anions, spatial variability of major ions, Total Hardness (TH) was employed to investigate the groundwater quality for drinking purposes. A total of 82 water samples were collected from different dug wells and hand pumps of the villages of Arajiline block in the pre monsoon season and analysed for pH, electrical conductivity, total dissolved solids (TDS), Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-} and CO_3^{-2}. The analytical data were compared with the Bureau of Indian Standards and World Health Organization standards to determine drinking water quality. Most of the surface water samples were found to be suitable as per the drinking water quality standards, but only an insignificant number of groundwater samples were unsuitable for drinking based on the concentration of major ions. Around 11% of the water samples are showing higher concentration of potassium in the groundwater which could be due to use of fertilizers.

Keywords: Major cations, spatial variability map, drinking water quality

Introduction
Monitoring groundwater quality has become mandatory in present century because of the impulsive development of the country focused on pri-urban and rural areas. About 50% of population in the world depends on using groundwater for their domestic needs (Connor, 2015) [17] whereas about 1.1 billion people have inadequate access to water. Groundwater has been a source of water supply in most of the developing nations since piped and treated water is not available and hence periodical groundwater quality monitoring is thus essential. India is one of the largest users of groundwater and about 100 million people live in areas having poor water quality (Rosegrant, *et al*., 2002) The variation of groundwater quality is due to the combined effects of geogenic and anthropogenic factors, such as the geology of groundwater storage, interaction between surface water groundwater-aquifer minerals, leaching of fertilizers from the surface and other human activities (Robins 2002; Mondal *et al*., 2010a, b; Wu *et al*., 2015; Mahlknecht *et al*., 2017) [21, 14, 15, 32, 11]. Groundwater quality assessment involves evaluation of parameters based on the permissible limits recommended by different organizations including the Bureau of Indian Standards (BIS), the U.S. Environmental Protection Agency (USEPA), and the World Health Organization (WHO), where, much focus is given to major ions. Many researchers have studied the quality of groundwater based on the concentration and spatial distribution of major ions (Robins 2002; Rajmohan and Elango 2004; Brindha and Elango 2011; Stamatis *et al*. 2011; Li *et al*. 2013; Chen and Feng 2013; Annapoorna and Janardhana 2015; Rajesh *et al*. 2015; Zahedi *et al*. 2017) [21, 20, 4, 24, 9, 5, 2, 19, 33]. The groundwater degradation occurs when its quality parameters are changed beyond their natural variations by the introduction or removal of certain substances. Groundwater has long been regarded as the pure form of water compared to surface water, because of purification of the former in the soil column through anaerobic decomposition, filtration and ion exchange like it's act as a role of water filtration unit vertically as well as laterally. However, it may have major toxic contaminants from the parent rocks or during the transportation and deposition process (Shiklomanov, 1998) [23].

Arajiline block is situated in the southern part of the Varanasi district, located in the eastern part of Uttar Pradesh. The area lies on the central Gangetic plain and the major part of the area consist of alluvial aquifers system. The alluvial aquifers constitute a hydrological unit formed by the alluvial deposits and are characterized by a linear and shallow feature as they are spread along the fluvial valley of the basin. The shallow character and high permeability of alluvial aquifers make them highly vulnerable to contamination (Garcia-Hernan, 1988) [16]. In the rural area of Varanasi where the livelihood depends on agricultural and small industrial activities, most of the peoples rely on hand pumps and dug wells for drinking purposes. Hence the present study was taken up to assess the quality of groundwater of Arajiline block of Varanasi for drinking purpose.

Study area

The study area is located in the Varanasi district of Uttar Pradesh, India, which comprises of two tehsils and 8 blocks (Arajiline, Bargaon, Chiraigaon, Cholapur, Harhua, Kashi vidhya peeth, Pindara, Sewapuri). The Varanasi district has a geographical area of 1535 km^2 and an elevation of 80.71 m and is situated in the centre of the Gangetic valley of North India and in the eastern part of the state of Uttar Pradesh. Varanasi experiences a humid subtropical climate (Köppen climate classification Cwa) with large variations between summer and winter temperatures. The dry summer starts in April and lasts until June, followed by the monsoon season from July to October. The temperature ranges between 22 °C and 46 °C in the summers. Winters in Varanasi encounter very large diurnal variations, with warm days and cold nights. Cold waves from the Himalayan region cause temperatures to dip across the city in the winter from December to February and temperatures below 5 °C are not uncommon. The average annual rainfall is 1,110 mm. Fog is common in the winters, while hot dry winds, called *loo*, blow in the summers. The study area is located at the crescent shaped bank of Ganges.

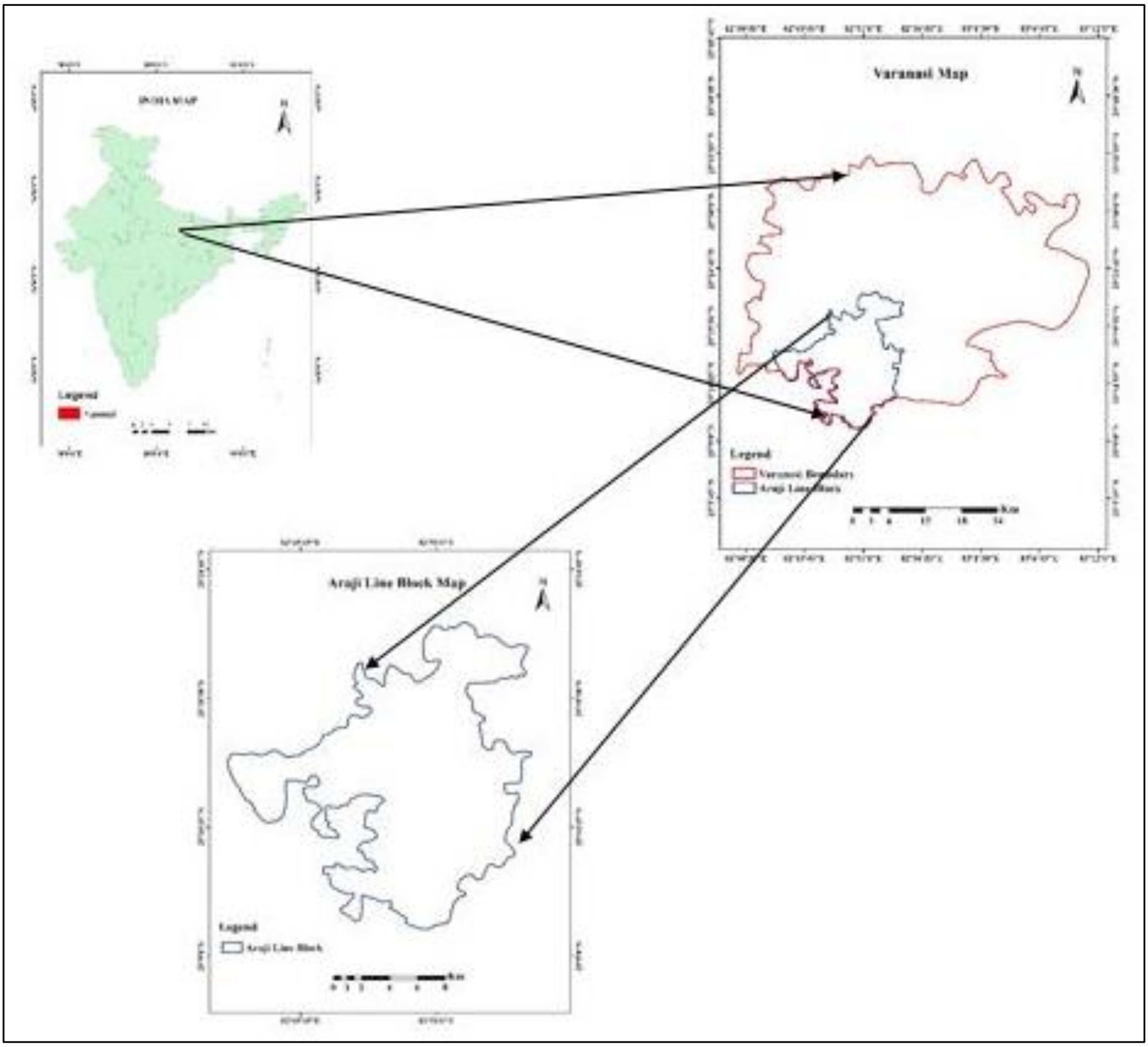


Fig 1: Study area map

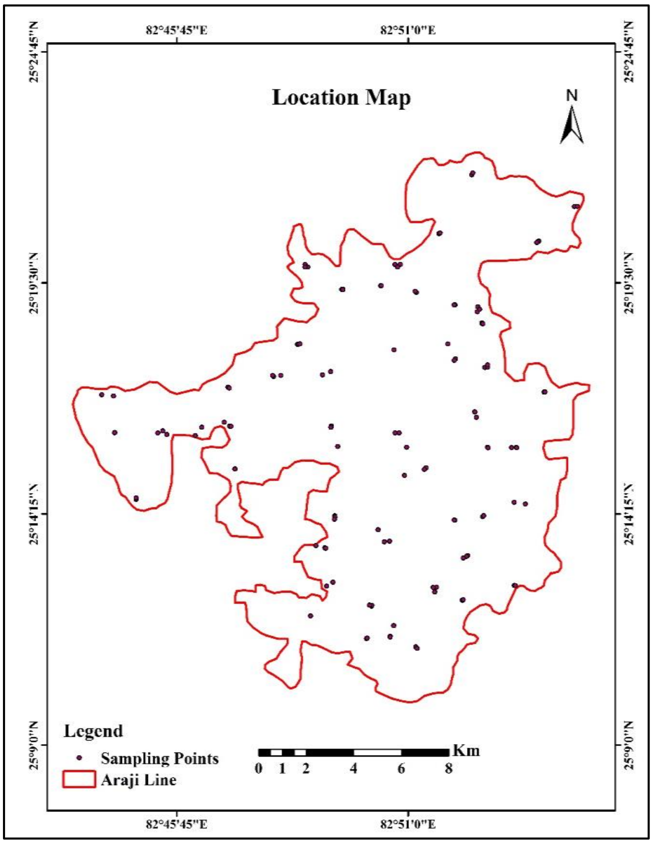


Fig 2: Location map showing the sampling points in the study area.

Geology of the study area

Geologically the study area is characterized by Quaternary alluvium consisting of older and younger alluvium, Upper Vindhyan to Upper Pleistocene to Recent age. Regarding the age of the formation, it is believed that deposition of the alluvium began with the upliftment of Siwaliks from Middle Pliocene to Pleistocene period and continued upto the present. The Indo-Gangetic depression must have come into existence during the later stages of the Himalayan orogeny. The formation of the depression, probably, began in Upper Eocene and attained its maximum during the third upheaval in the Middle Miocene. Since then gradual filling of sediments made it into a level plain with a very gentle seaward slope (Ahmad, 1993) [1].

Table 1: Stratigraphic sequence of the study area.

Age	Formation	Lithology
Upper Pleistocene to Recent	Newer Alluvium	Clay, Sand and Kankar
Middle to Upper Pleistocene	Older Alluvium	Fairly consolidated clay with Kankar, sand, fine medium with some gravel.
---------------------------- Unconformity ----------------------------		
Upper Vindhyan	Kaimur Sandstone	Sandstone gray to white, buff, arkosic with capping of laterites and Bauxite

Material and methods

Water samples were collected from the Arajiline block in the period from March 20th to 9th April, 2018 during the pre-monsoon season. The samples from the wells and hand pumps were collected from fifty-one villages of Arajiline block. The samples were collected in a systemic way and geo-referenced with the help of GPS (Garmine 64s). The hand pumps and tube wells were continuously pumped for 10 minutes prior to sampling to ensure that ground water to be sampled was representative of the aquifer. Water samples from open wells were taken at a depth with the help of rope avoiding the water present at the surface. All the samples were stored in 500 ml plastic bottles which were cleaned by soaking in 1:1 diluted HNO_3 overnight. Additionally, these bottles were washed again with distilled water before sampling. Further, the bottles were rinsed 2-3 times with the water samples to be collected. The water samples were filtered using 0.45-µm filter paper before detailed chemical analysis. Detailed laboratory analysis was carried out in the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.

Laboratory Analysis

The pH was measured with a digital pH meter using a reference electrode. The pH meter was calibrated with help of buffers tablets of pH 4.0, pH 7.0, and pH 9.2 respectively. The electrical conductivity was measured with E.C. meter. The E.C. meter was standardized prior to use with the 0.01 N KCl solution and the reading of the E.C. meter is adjusted to 1.40 µS/cm. Thereafter, 25 mL of water sample was taken in a disposable plastic cup and stirred constantly with magnetic stirrers before taking readings. The total dissolved solids (TDS) comprise of inorganic salts and a meager number of organic compounds. TDS were calculated using the formula TDS (mg/l) = Electrical Conductivity (µS/cm) × 0.64 (Lloyd and Heathcote, 1985) [10]. Carbonate and bicarbonate was estimated by acidimetric titration using suitable indicators. Carbonate and bicarbonate in water was determined by titrating the water with standard sulphuric acid (0.01**N**) using phenolphthalein and later on methyl orange as indicators. Chloride was estimated based on the titration of neutral chloride solution with neutral silver nitrate solution in the presence of potassium chromate (K_2CrO_4) as indicator. Sulphur was determined turbidimetrically as barium sulphate (Massoumi and Cornfield, 1963) [12]. The total Ca^{2+} and Mg^{2+} was determined using complexometric titration, involving ethylene diamine tetra acetic acid (EDTA). The sodium and potassium content of the water samples were measured by direct determination in a flame-photo meter (Model-Elico-Cl-361) using sodium and potassium filters after standardization with sodium and potassium standards. The results were analysed statistically to arrive at valid conclusions.

Result and discussion

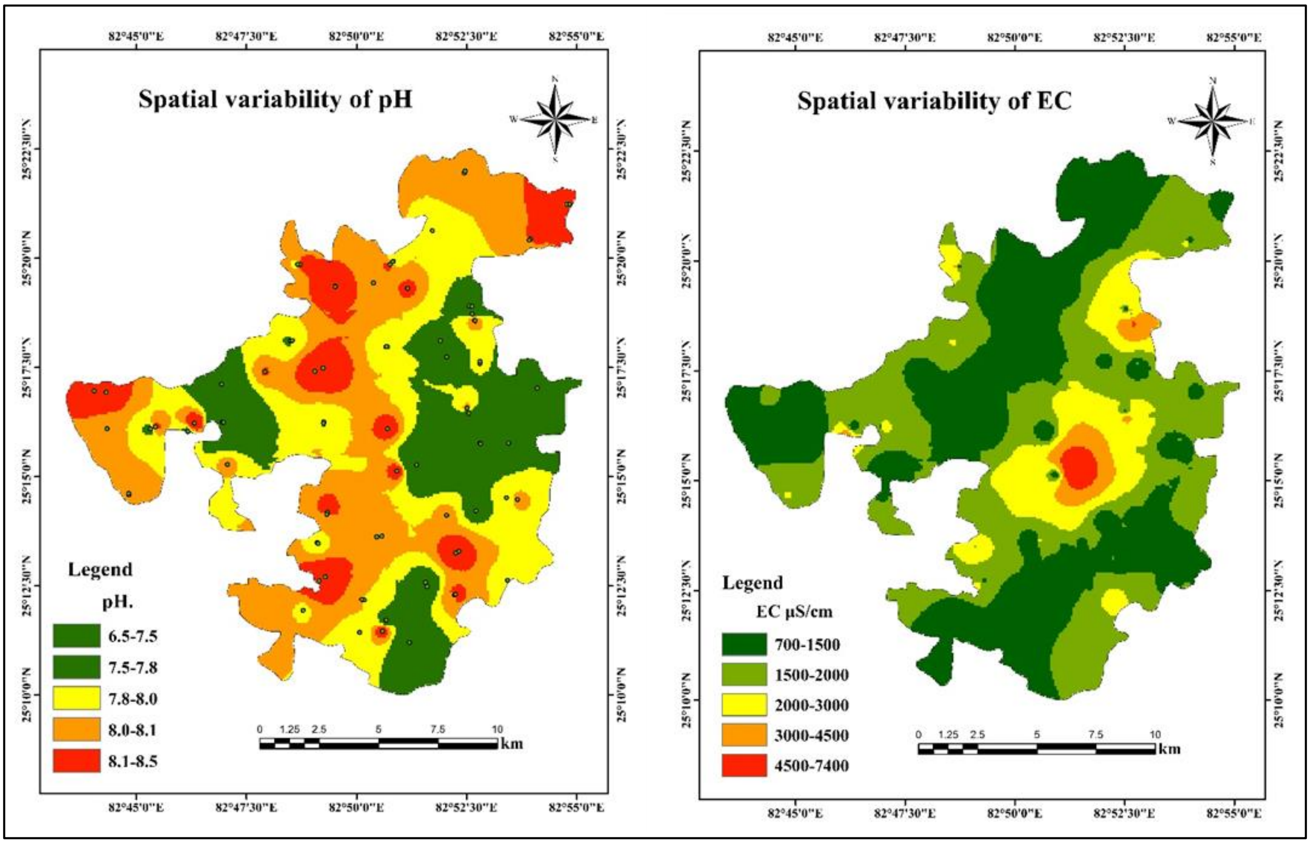
Groundwater collected from the 82 locations of the Arajiline block was systematically analysed and the maximum, minimum, and standard deviation values obtained for various parameters is presented in the Table 2.

Table 2: Summary of measured chemical characteristics of groundwater and comparison with WHO/BIS standards

Parameter	Groundwater (Total No of samples=82)						
	Mini	Max	Mean	Std. dev	WHO standards /permissible limit	BIS standards / permissible limit	No of samples exceeding the permissible limit
pH	6.3	8.6	7.9	0.4		8.5	4 (5%)
EC (µS/cm)	710	10660	1748	1301.9		-	
TDS (mg/L)	454.4	6822.4	1119.1	833.2		2000	8 (10%)
Calcium (mg/L)	6	110	12.2	12.4		200	-
Magnesium (mg/L)	4.8	152.4	19.5	17.8		100	1
Sodium (mg/L)	12.8	78.4	45.5	17.1	200		-
Potassium (mg/L)	0.2	66	6.1	10.2	12		9 (11%)
Chloride (mg/L)	35.4	1701.6	166.9	196.5		1000	1
Sulphate (mg/L)	18.4	572	48.7	67.6		400	1
Carbonate (mg/L)	-	84	22.2	18.5		-	
Bicarbonate (mg/L)	6.1	762.5	181.1	101.3		600	1

pH and electrical conductivity

The pH of the ground water was found to be slightly alkaline in nature, and 95% of the groundwater samples in the study area were within the standard drinking water quality BIS (2012) [3] (Table 2). The pH in eastern reaches of the block was normally low whereas highly alkaline water was found towards the western and the middle part of the block. High pH in water causes bitter taste and eye and skin irritation (WHO, 2007). EC is a good indicator in assessing water quality. In general, groundwater will have more dissolved ions than surface water, which holds true for this area too, and the EC of groundwater was always higher than the surface water. EC of groundwater in lower and middle regions of the block was high in concentration and the groundwater (well and hand pump water) from the Asvari village showed very high concentration of EC. Higher values of EC reduces the aesthetic appearance of water and are also sensitive to infants and heart patients (WHO, 2003c). Spatial variability of pH and EC is shown in the figure 3.



a. b.

Fig 3: Spatial variability map of pH (a) and EC (b) of Arajiline block of Varanasi

Total dissolved solids

The total dissolved solids (TDS) encompass inorganic salts and a small number of organic compounds. TDS were calculated using the formula TDS (mg/l) = Electrical Conductivity (µS/cm) × 0.64 (Lloyd and Heathcote, 1985) [10]. The desirable limit for TDS in drinking water is 500 mg/l as per BIS (2012) [3]. Out of the total number of samples collected, 90% of the samples were within the desirable limit of drinking water quality and 10% of water samples were outside the desirable limit of drinking water quality, which is

2000mg/l as per the BIS (2012) [3] norms. Classification of water was made based on TDS (Table 3), as suggested by Freeze and Cherry (1979) [6] which shows that out of the total number of samples collected, 38% of the groundwater samples fell into the brackish water category (TDS>1000 mg/l) and 51% of the groundwater samples are in fresh water category (TDS<1000 mg/l). None of the samples were saline or in the brine category. The spatial variability map of TDS is shown in the Figure 4. The distribution followed the pattern of electrical conductivity with extreme values in the center and upper right of the block.

Table 3: Classification of water based on TDS

Category Freeze and Cherry (1979) [6]	TDS mg/L	Groundwater samples
Fresh	<1000	51 (62%)
Brackish	1000-10,000	31 (38%)
Saline	10,000-100,000	0
Brine	>100,000	0

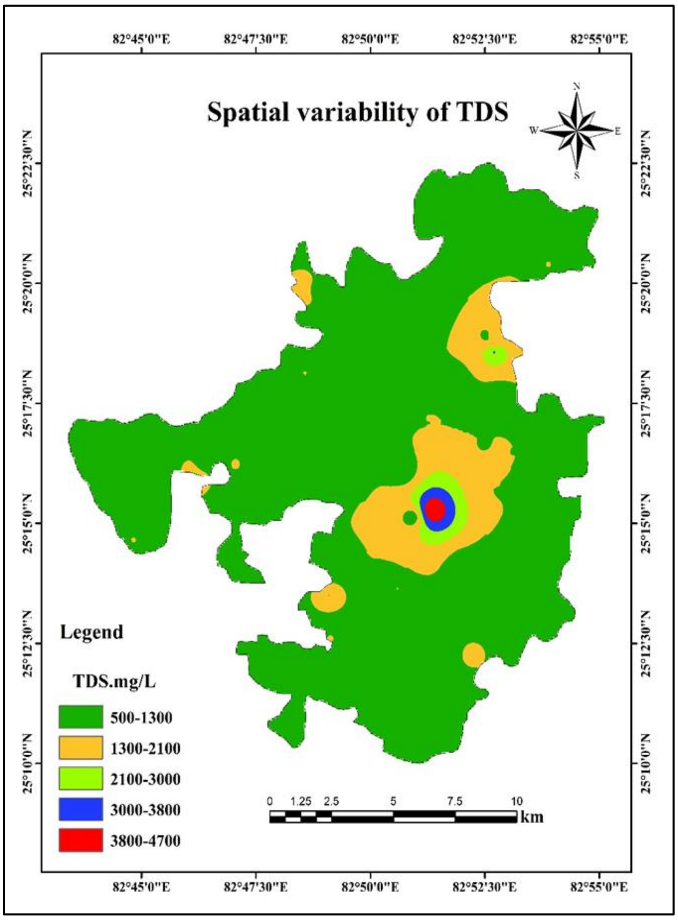


Fig 4: Spatial variability map of TDS for Arajiline block of Varanasi.

Major cations and anions

Major cations and anions are important to understand the quality of groundwater. Major cations (Ca, Na, Mg, K) and anions (HCO_3, SO_4, Cl) of groundwater were used to plot the Piper trilinear plot (Piper, 944) (Fig 5.) to understand the types of water. From the plot, it is evident that groundwater fit into the Ca–Mg–Cl type of plot. The plot shows a slight shift towards Ca-Na–HCO_3 type of samples. The dominance of major ions was in the order of Na > Ca > Mg > K and HCO_3> Cl > SO_4 for groundwater. The calcium concentration of groundwater in 99% of the water samples was below the desirable limit of 75 mg/l BIS (2012) [3] except for 1% of water samples. Calcium in groundwater is mainly due to ion exchange during the interaction of minerals from rock. Increase in calcium concentration affects the absorption capacity of the human body. The magnesium concentration in groundwater may have originated from silicate weathering. Out of the 82 groundwater samples collected, 75 samples were below the desirable limit of 30 mg/l (BIS, 2012) [3] except for 1% of water samples. Na may cause hypertension, and high Na (NaCl) may cause vomiting, muscular twisting, rigidity. Sodium concentration in the groundwater reveals that the water to be suitable for the drinking purposes as per the WHO (2003a) [27] norms.

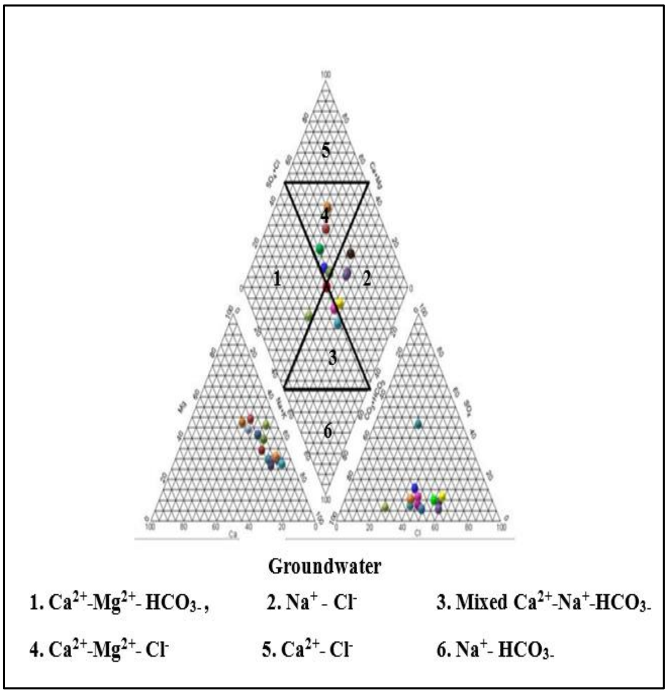


Fig 5: Piper plot of groundwater

The maximum concentration of potassium shown in the groundwater was 66 mg/l and 11% of the water samples exceeded the permissible limit of 12 mg/l as per WHO (2011) [30] norms. Potassium in water is mainly due to agricultural run-off and also due to weathering of rocks. Some of the studies have documented that higher concentration of potassium causes blood pressure in the human beings. The spatial distribution of potassium is shown in figure 6. The bicarbonate concentration was generally high for groundwater but was below the permissible limits of 600 mg/l (BIS, 2013). The maximum concentration of bicarbonate was 762.5 mg/l and minimum value identified was 6.1mg/l and 1 water sample exceeded the permissible limit of BIS (2012) [3] among the groundwater samples analysed. The chloride concentration in groundwater was high in 1 water sample as per the BIS (2012) [3] drinking water quality and 88% of the water samples are under the desirable limit. The chloride in groundwater is contributed by both natural and anthropogenic sources, such as run-off containing fertilizers, landfill leachates, industrial and sewage effluents, irrigation drainage (WHO, 2003b) [28]. About 98% of the groundwater samples of the Arajiline block exhibited sulphate concentrations which was normally below the desirable limit of 200 mg/l as suggested by the BIS standards BIS (2012) [3] and only 2% of the samples exceeded the maximum permissible limits of drinking water quality. Sulphates occur naturally in numerous minerals, including barite ($BaSO_4$), epsomite ($MgSO4·7H_2O$) and gypsum ($CaSO_4·2H_2O$). On the other hand sulfates and sulfuric acid products are used in the production of fertilizers, chemicals, dyes, glass, paper, soaps, textiles, fungicides, insecticides, astringents and emetics. They are also used in the mining, wood pulp, metal and plating industries, in sewage treatment and in leather processing Greenwood & Earnshaw, (1984) [7].

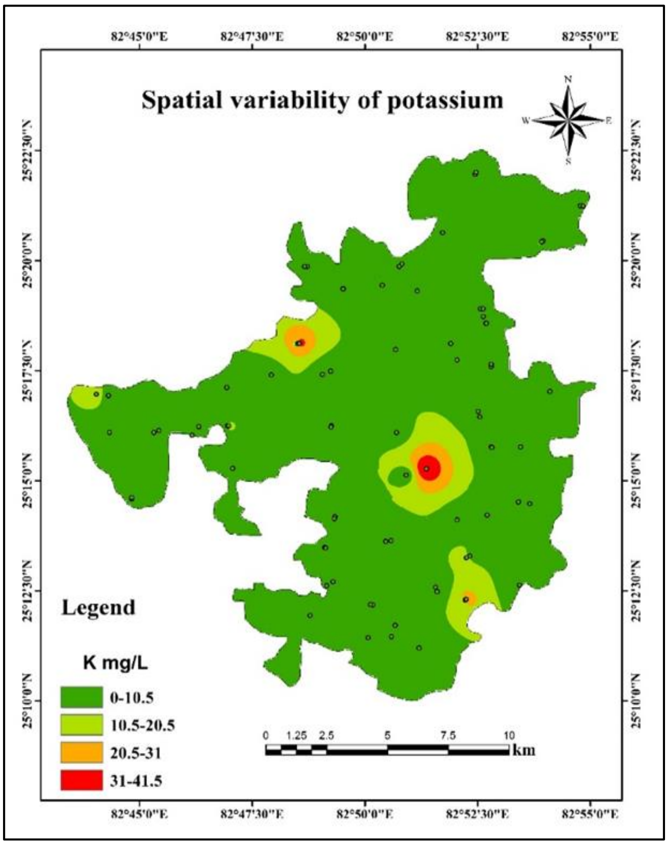


Fig 6: Spatial variability of potassium in Arajiline block of Varanasi.

Total hardness (TH)

The hardness of water is caused by the carbonate and noncarbonated salts of calcium and magnesium. Total hardness was estimated using the following relation (Todd, 1959) [25].

$$\text{Total Hardness (mg/l)} = (2.5 \times Ca) + (4.1 \times Mg)$$

where the concentrations of Ca and Mg are in mg/l. TH expressed in terms of $CaCO_3$ varied between 34.7–901.8 mg/l for groundwater. The total hardness for most of the groundwater samples was less than the permissible limit of 600 mg/l as suggested by BIS (2012) [3], except for 1 water sample. According to Sawyer and McCarty (1978) [22] classification (Table 4), 67% of the groundwater samples come under moderately hard to hard water category and only 2% of the groundwater samples fall under very hard water category. TH in water is he sole reason for scaling of boilers. Recent studies suggest a positive relationship between hardness, cardiovascular issues and kidney ailments (WHO, 2011) [30]. The spatial variability map of TH is shown in the Figure 7.

Table 4: Classification of water based on the hardness

Category Sawyer and McCarty (1978) [22]	Hardness (mg/l of CaCO3)	No of Groundwater samples
Soft	<75	25 (31%)
Moderately hard	75-150	47(57%
Hard	150-300	8(10%)
Very hard	>300	2(2%)

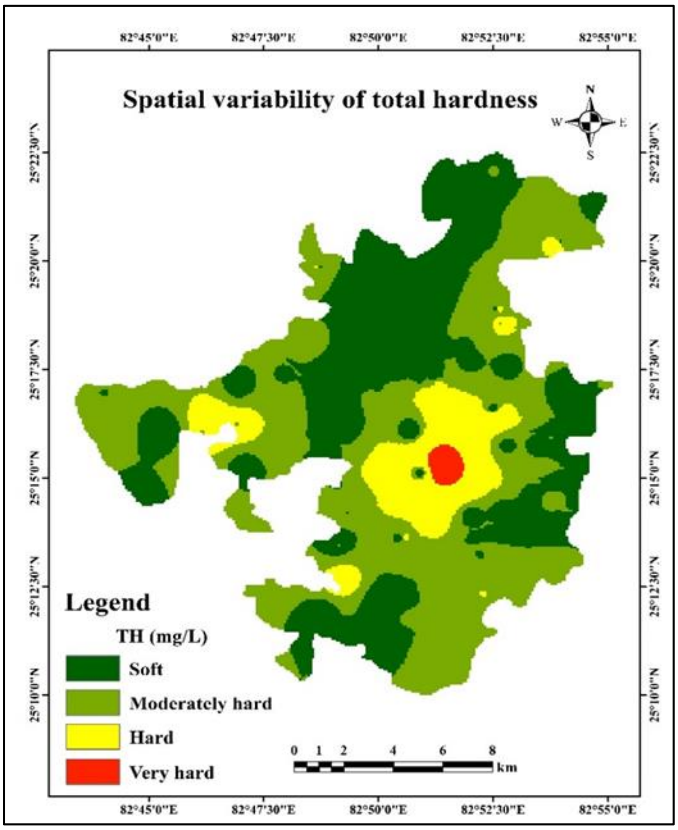


Fig 7: Spatial variability map of total hardness in groundwater

Conclusion

The study reveals that most groundwater fall under the Ca-Mg-Cl type and the dominance of major ions was in the order of Na > Ca > Mg > K and HCO3 > Cl > SO4. Most of the groundwater comes under brackish water category based on TDS and some falls under the hard water category. Some of the shallow water aquifers (open wells) belongs to the very hard category. Hence, when we consider the physicochemical parameters and compare them with WHO and BIS standard for the drinking water quality, it is brought into light that 5% of the water samples exceeded the permissible limit of pH and 10% of the water samples exceeded the permissible limit of TDS. 11% of groundwater samples are exceeding the permissible limit for potassium which could probably be because of agricultural use of potassic fertilizers in the area. Based on the analysis of cations and anions, it can be inferred that most of the water samples are good for drinking purposes as per the BIS and WHO norms except the Asvari village shows higher values for groundwater than the prescribed limit by the WHO (2011) and BIS (2012) [3] standard.

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