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A Regression-Based Analysis to Assess the Impact of Fluoride Reach River Water on the Groundwater Aquifer Adjacent to the River: A Case Study in Bharalu River Basin of Guwahati, India

Das, M. and Bhattacharjya, R.K.*

Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati 781 039, Assam, India

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ABSTRACT: Fluoride is one of the parameters which is non-degradable and naturally occurring inorganic anion found in many natural streams, lakes, and groundwater. Serious problems are faced in several parts of India due to the high consumption of fluoride through drinking water. These may cause dental and skeletal fluorosis to humans. This study aims to examine the level of fluoride in both Bharalu river water and groundwater within Guwahati city, Assam, India, and also to analyze the impact of fluoride reach river water on the groundwater aquifer adjacent to the river. From the investigation, it has been observed that the concentration of fluoride varies from 0.02 to 3.73 mg/l in river water and 0.04 to 4.7 mg/l in the case of groundwater. The statistical analysis shows that there is a strong correlation between the fluoride concentration of river water and groundwater. This indicates that the groundwater might have contaminated by the polluted river water.

Keywords: Contamination; Correlation; Surface water; Mineralogical.

INTRODUCTION

Water is considered to be an essential natural resource for the survival of life and the environment. With the increasing rate in population, people are more concerned about the quality surface and groundwater sources as they are getting polluted day by day. It has been observed that many surface water sources are getting polluted due to the dumping of municipal, domestic, and industrial waste. Moreover, the percolation of these wastes or polluted water is also contaminating the groundwater aquifer. Agricultural runoff, toxic chemical leaks, sewage leaks, and an abundance of bacteria and harmful pathogens are some of the significant sources of surface water and groundwater pollution. Further, the interaction of surface water and groundwater is one of the major issues of contamination to aquifers. The interaction between the river water and groundwater aquifer is challenging to observe and measure. Thus this issue has been generally ignored in many water-management considerations and policies.

Generally, the groundwater table is higher than the river water level, and there is a natural flow of groundwater to the river. However, in the case of Guwahati city, the groundwater table has been depleted year after year. The data collected from the Central Groundwater Board shows that the groundwater table is depleting in Guwahati. Figure 1 shows the depth of the groundwater table at the Zoo Narangi location of Guwahati. The

* Corresponding Author, Email: rkbc@iitg.ac.in

recorded data is showing that the groundwater table is depleting at an average rate of 20 cm per year. As observed, during the rainy season, the river water is almost at the ground level. As a result, the flow of water may be occurring in the reverse direction, i.e., from the river to the groundwater aquifer. The problem can be compared to the saltwater intrusion problem in a coastal aquifer. In the case of the polluted river, the polluted river water may contaminate the groundwater aquifer.

River water pollution has become a serious issue in India. Many rivers such as Ganges (Singh, 2001; Mishra, 2010), Hooghly (Mondal, 2018), Krishna (Sekhar & Umamahesh, 2004), Tapti (Shah et al., 2013), and Brahmani (Sundaray, 2010) are getting polluted day by day. In Assam, the Bharalu, a small tributary of the mighty Brahmaputra, is flowing through the heart of populated Guwahati city. The river used to carry fresh water (up to around 1970) and was a source of potable water for the people living on the banks of the river. However, over time, the river has been converted to a main drain of the city (Figure 2). The river carries a large portion of the municipal as well as other wastes of the city and discharges it in the river Brahmaputra (Girija et al., 2007; Hussain et al., 2015). The river is now highly polluted, and the water quality is far below the drinking standard. As reported, fluoride concentration, more than the permissible limit (1.5 mg/l), has been found in some parts of Guwahati city (Das et al., 2003; Chakraborty et al., 2009). Fluoride concentration in groundwater may increase due to the passage of groundwater through fluoride-rich rocks. However, for the Bharalu river basin, it has been seen that the concentration of fluoride is also high in the river water. The high concentration of fluoride in the groundwater near the river may be due to the intrusion of polluted river water into the aquifer, hydraulically connected to the river. As such, a regression-based analysis has been carried out to evaluate the impact of polluted river water on the groundwater aquifer adjacent to the river.

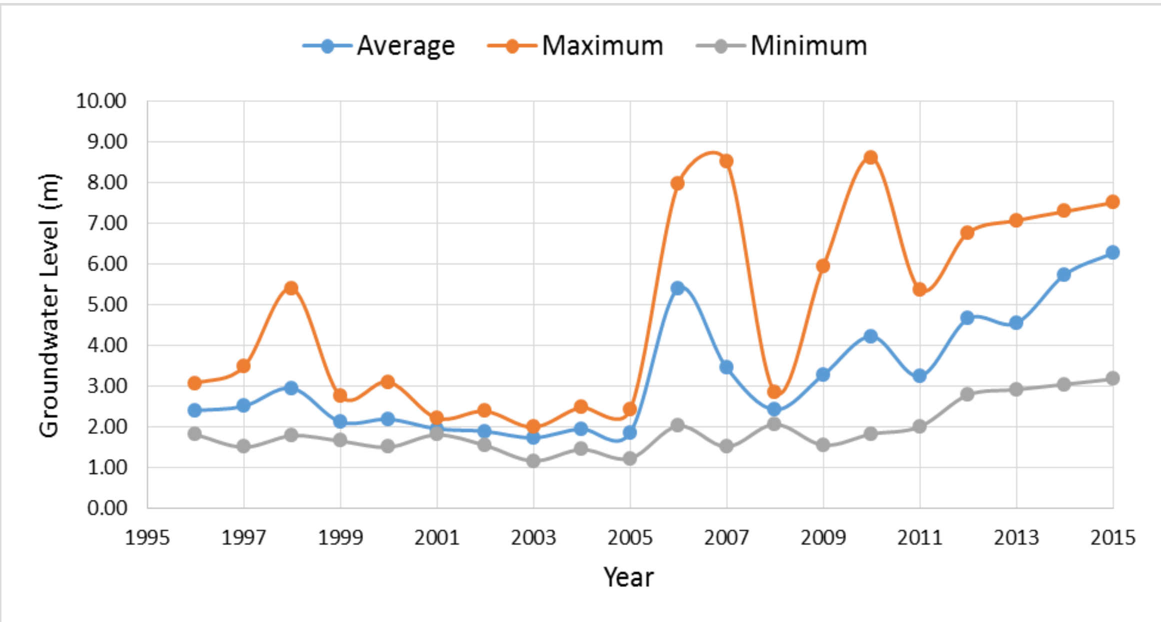


Fig. 1. Depth of groundwater water table at Zoo Nagangi location of Guwahati

Fig. 2. The present condition of the Bharalu River

Several studies in Assam have been conducted for mapping groundwater contamination by fluoride. Borah et al. (2010) studied the contamination of drinking water by lead, arsenic, fluoride, and iron. The study area was the tea garden belt of Darrang district of Assam. Dutta et al. (2006) studied the fluoride contamination in groundwater of Central Assam. Kakoty et al. (2008) studied the distribution of fluoride and endemic fluorosis in Karbianglong district of Assam. Sharma et al. (2012) evaluated the quality of groundwater with an emphasis on fluoride concentration in Nalbari district of Assam. Buragohain et al. (2008) studied the fluoride, arsenic, and iron in groundwater of Dhemaji district of Assam. Chakraborty et al. (2009) studied the fluoride in the drinking water of Guwahati city and also suggested a plan for effective removal techniques. Borah et al. (2001) indicated a gradual deterioration of groundwater quality due to surface water-groundwater interaction along the polluted stretch of the river Bharalu. It has been reported that high fluoride concentration found in the southeastern plains of the city (Das at el., 2003). Sarma & Bhattacharyya (1999) studied the nitrate and fluoride content in drinking water of Darrang district of Assam. Borah & Dey (2009) provided a fluoride removal technique using low-grade coal.

Several other places in India are also affected by fluoride contamination. Ali et al. (2018) studied the fluoride contamination in groundwater of Siwani Block of Western Haryana. They also evaluated their impact on sustainable water supplies for drinking and irrigation. Adimalla et al. (2018) evaluated the groundwater quality in Peddavagu in Central Telangana (PCT), India. Adimalla et al. (2019) did a case study to assess fluoride contamination and its distribution in the rural part of Andhra Pradesh. Kundu et al. (2001) reported the fluoride contamination of groundwater in Nayagarh District of Orissa. Some other studies reporting fluoride contamination in India are Narsimha and Sudarshan (2017), Rao (2008), Rao et al. (2017), Shivashankara et al. (2000), Ayoob and Gupta (2006), Mamatha and Rao (2010), Muralidharan et al. (2002), *etc*.

The fluoride contamination of groundwater and surface water is also a major concern in several parts of the world. Amini et al. (2016) reported the spatial and temporal variability of fluoride concentrations in groundwater resources of Larestan and Gerash regions in Iran between 2003 to 2010. Battaleb-Looie et al. (2012) did the hydrogeochemical evolution of groundwaters with excess fluoride concentrations from Dashtestan of Iran.

Brouwer et al. (1988) evaluate the unsuitability of WHO guidelines for fluoride concentration in drinking water in Senegal. Dissanayake (1991) studied the fluoride problem in the groundwater of Sri Lanka. Farooqi et al. (2007) studied the toxic fluoride and arsenic-contaminated groundwater in the Lahore and Kasur districts of Punjab, Pakistan. They have also obtained the possible contaminant source of contamination of groundwater aquifer. Rafique et al. (2009) studied the geochemical factors which control the occurrence of high fluoride groundwater in the Nagar Parkar area, Sindh, Pakistan. Gikinju et al. (2002) studied the contamination of river water in Kenya by fluoride. Rosso et al. (2011) studied the occurrence of fluoride in arsenic-rich surface waters. A case study was conducted in the Pampa Plain, Argentina. Tohyama (1996) studied the relation between fluoride concentration in drinking water and mortality rate from uterine cancer in Okinawa prefecture, Japan. Valenzuela-Vásquez et al. (2006) studied the origin of fluoride in groundwater supplied to Hermosillo City, Sonora, México. Wu et al. (2015) did a study for the characterization of drinking groundwater with particular reference to fluoride in an arid area of China. Yang et al. (2000) studied the relation between fluoride in drinking water and cancer mortality in Taiwan.

The review of the literature shows that several studies have been conducted to study the special and temporal variation of surface water and groundwater aquifer contamination. However, the interaction between the polluted surface water source and groundwater has not been studied for many surface water pollution sources. One such location is the Bharalu river basin in Guwahati city of Assam, India. This study aims to examine the level of fluoride in both Bharalu river water and groundwater aquifer within Guwahati city and their interaction using a regression-based analysis.

MATERIAL AND METHODS

The study is carried out in the Bharalu river basin in Guwahati city of Assam, India (Figure 3). It covers an area of approximately 40 square kilometers and lies between 25°59′ to 26°11′ N and 91°43′ to 91°51′ E. Topographically, the area is consist of hills and plans with some bloated hillocks. The city rests upon the typical Precambrian rock units, which are overlain by young and recent alluvium. The river Bharalu, one of the smaller tributaries of the river Brahmaputra, is passing through the heart of Guwahati city. The river once used as a source of potable water. However, the unplanned urbanization has converted the river as one of the major drains of the city. In the absence of centralized sewage treatment plant, sewage, untreated industrial effluent, municipal solid wastes and domestic wastes of the city is directly discharged into the river Bharalu. Thus the river Bharalu carries the polluted water of the city and releases it to the river Brahmaputra at Bharalumukh. At present, the river Bharalu water is exceptionally contaminated, including a high concentration of fluoride and is also contributing to the pollution of the river Brahmaputra. Further, there is also a strong exchange of water between the river and the groundwater aquifer adjacent to the river. As such, the polluted river water has also entered into the groundwater aquifer and polluted the groundwater. It has been reported that the concentration of fluoride in the river Bharalu water is much higher than the permissible limit. As per the second edition of WHO Guidelines for Drinking-water Quality (2004), Fluoride is a heavily contested element as it affects the lives of millions of people around the world in a variety of ways. The excessive consumption of fluoride through drinking water may result in fluorosis, renal impairment and may cause cancer in human bone. Excessive consumption can also create an adverse effect during pregnancy. There are some areas in the city where fluoride concentration in groundwater was found to be above 1 mg/l. As reported (Sharma et al., 2005), excessive fluoride contamination in groundwater has resulted in fluorosis in several localities of Guwahati.

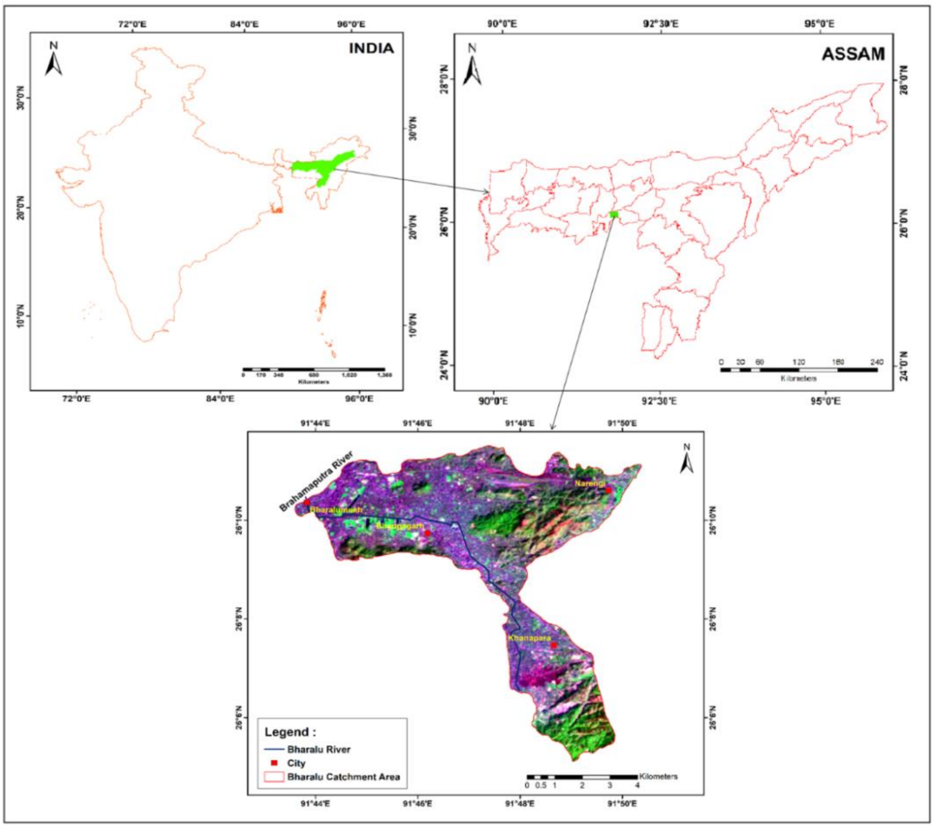


Fig. 3. Map showing the Bharalu River flowing through the Guwahati City, Assam, India

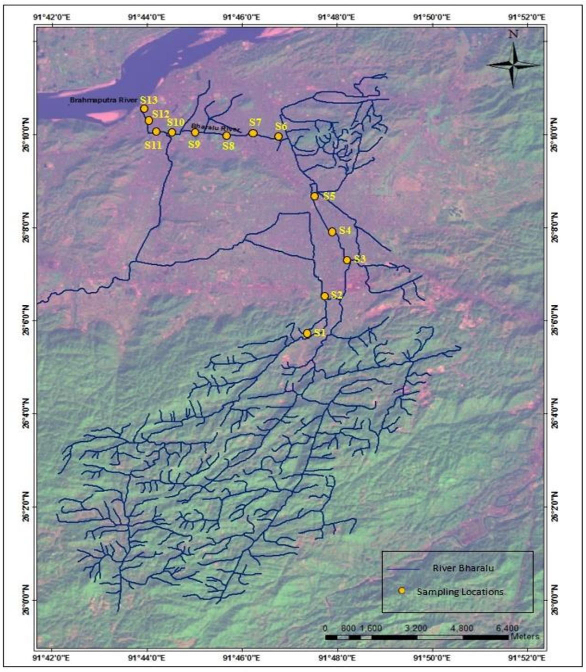


Fig. 4. Sampling locations along the river Bharalu

Table 1. Sampling location from upstream to downstream site of the river

Sampling point (L)	Sampling location	Latitude & longitude
L1	Basistha Mandir	$26^0$5'41.64"N & $91^0$47'06"E
L2	Natun Bazar, Basistha	$26^0$60'30.96"N & $91^0$47'51"E
L3	Bhetapara	$26^0$7'3.36"N & $91^0$47'3.48"E
L4	Beltola	$26^0$7'42.96"N & $91^0$48'4.68"E
L5	Rukminigaon	$26^0$8'10.32"N & $91^0$47'48.48"E
L6	Jonali	$26^0$7'59.16"N & $91^0$49'8.4"E
L7	Anilnagar	$26^0$10'5.88"N & $91^0$46'14.16"E
L8	Ulubari	$26^0$10'5.88"N & $91^0$45'14.76"E
L9	Chabipool	$26^0$10'10.2"N & $91^0$44'42.72"E
L10	Athgaon	$26^0$10'23.52"N & $91^0$44'21.84"E
L11	Fatasil	$26^0$9'58.68"N & $91^0$44'12.12"E
L12	Sluice-gate	$26^0$10'9.12"N & $91^0$43'52.32"E
L13	Bharalumukh	$26^0$10'27.48"N & $91^0$43'59.52"E

The present study examines the fluoride level in both river water and groundwater within Guwahati. Water samples, both surface water, and groundwater were collected from different locations, as shown in Figure 4, and Table 1 shows the geographic location of the sampling sites. The water samples were collected from thirty-five different locations of the domestic waste site, twenty-one different locations of the municipal waste site, twenty-five different locations of the commercial waste site, and seven different locations of the industrial waste site.

Water samples were collected from the locations shown in Figure 4. The samples were collected from the river and also from the tube well adjacent to the river Bharalu. The water samples were collected during the wet and dry seasons in a pre-cleaned plastic bottle of 2.5 liters capacity. Plastic bottles are rinsed several times with distilled water and dried thoroughly before the collection of the sample. The experimental study is carried out as per standard methods prescribed by (APHA, 1995). According to this, the concentration of Fluoride in the water samples is measured by SPADNS method. The intensity of the color formation is inversely proportional to the fluoride content present in the water samples. The readings are taken directly on UV-VIS Spectrophotometer at 570 nm. The measured concentration is compared with the Standard value of the water quality parameter for drinking water. As per IS: 10500: 2012, the Permissible Limit of Fluoride in the absence of alternate sources is 1.5 mg/l.

Table 2. The significance of the R^2 value (Sanchez, 2012)

Sl. No.	*R* value	Remarks
1	$0.7 < R^2 < 1$	Strong
2	$0.4 < R^2 < 0.7$	Medium
3	$0.2 < R^2 < 0.4$	Small
4	Less than 0.2	None

A regression analysis has been carried out to study the impact of surface water on groundwater. For finding the relationship between two parameters X and Y, Karl Pearson's correlation coefficient (R) is used, and their linear relation is determined in the form of the following equation.

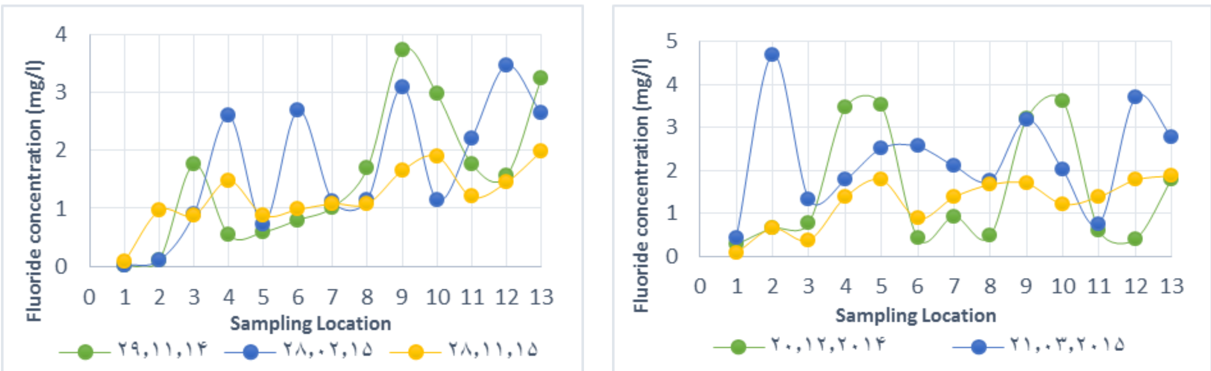
$$Y = a + bX \quad (1)$$

Here, Y is the dependent variable; X is the independent variable a is the intercept, b is the slope intercepting the y-axis. The higher the value of the regression coefficient (R^2) indicates the better fit. Table 2 shows the significance of the (R^2) -value

RESULTS AND DISCUSSIONS

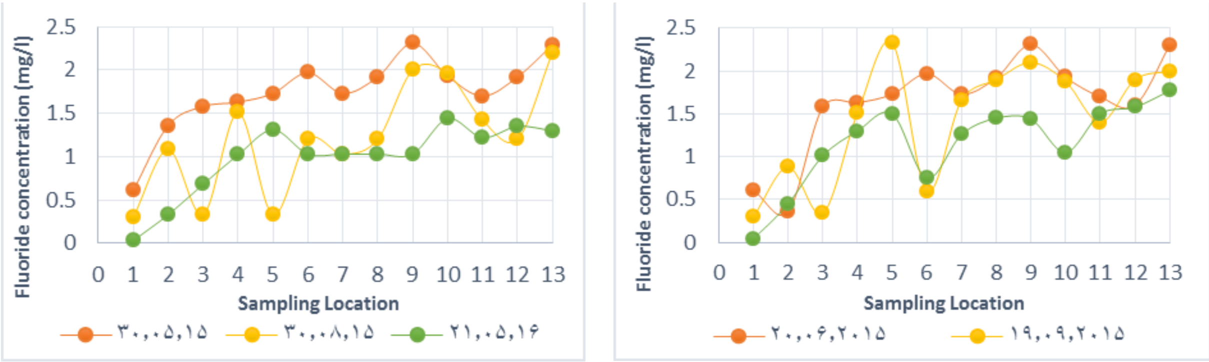
The result obtained after the analysis is described graphically from Figure 5 and 6. The graphs are plotted with sampling location along the X-axis and concentrations along the Y-axis. The variation of the surface water and groundwater fluoride concentration in the dry season is shown in Figure 5. From the figure, it can be observed that the concentration of fluoride ranges between 0.3 and 3.73 mg/l with an average value of 1.42 mg/l.in surface water. For groundwater, the concentration ranges from 0.08 to 4.7 mg/l, with an average value of 1.36 mg/l. The Fluoride concentration is high in almost all the samples, but the samples collected from the upstream site near Basistha Mandir is within the permissible limit. The highest value (3.73 mg/l) of fluoride was recorded in the Chabipool location. The lowest value (0.08 mg/l) was recorded near Basistha Mandir. In the case of groundwater, the highest value (4.7 mg/l) of fluoride was recorded in Natun Bazar, Basistha location. The lowest value (0.08 mg/l) was recorded near Basistha Mandir. From the investigation, it has been noted that the fluoride concentration in both surface water and groundwater increases from the upstream site to downstream site with some variation in the middle course.

The variation of the surface water and groundwater fluoride concentration in the wet season is shown in Figure 6. During the wet season, the fluoride concentration ranges between 0.03 and 2.31 mg/l, with an average value of 1.42 mg/l in surface water. Whereas in groundwater, it ranges from 0.04 to 2.33 mg/l with an average value of 1.36 mg/l. At the upstream site near Basistha Mandir, the fluoride concentration is found to be within its permissible limit. The high value (2.31 mg/l) of fluoride was recorded in the Chabipool location. The lowest value (0.03 mg/l) was recorded near Basistha Mandir. In groundwater, the high value (2.33 mg/l) of fluoride was recorded in Rukminigaon location. The lowest value (0.04 mg/l) was recorded near Basistha Mandir. The study shows that the fluoride concentration in both surface water and groundwater increases from upstream sites to downstream sites with some variation in the middle course, which may be due to some interconnected drains from the different dumping site. Further, comparison of the data of dry and wet seasons shows that the fluoride concentration is lesser in the wet season as compared to the dry season. This is due to the dilution happening in the rainy season. Figure 7 shows the box plot showing the minimum, maximum, and average value of Fluoride concentration in different sampling locations of surface water and groundwater.



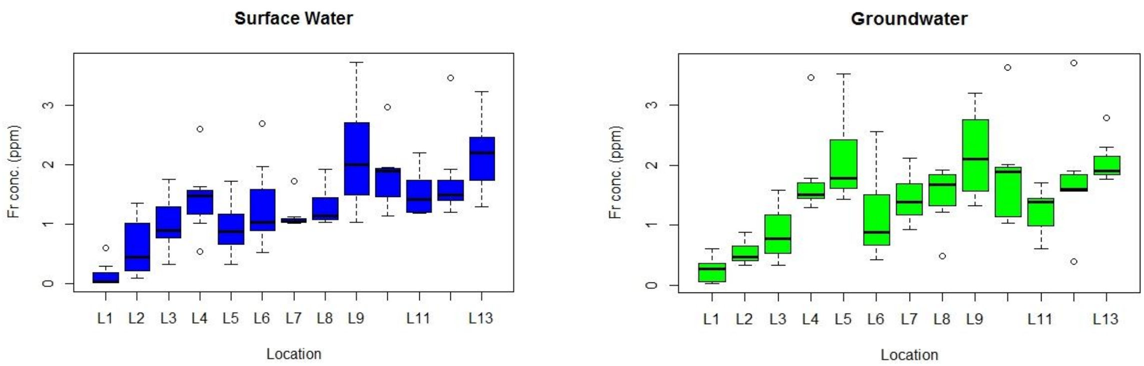
(a) (b)

Fig. 5. Variation of the fluoride concentration in the dry season a) surface water and b) groundwater



(a) (b)

Fig. 6. Variation of the fluoride concentration in wet season a) surface water and b) groundwater.



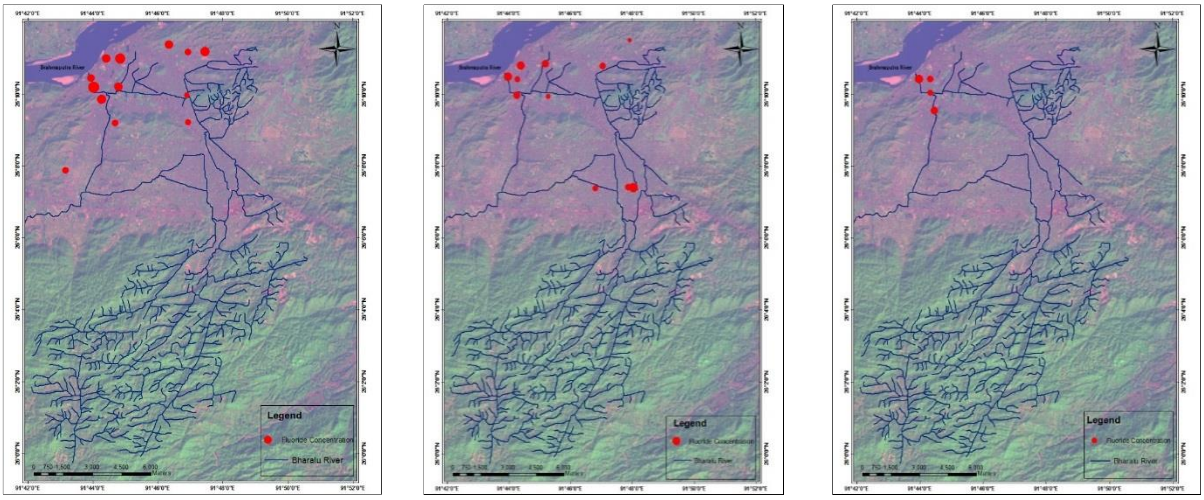
(a) (b)

Fig. 7. Box plot showing the minimum, maximum and average value of Fluoride concentration in different sampling locations (a) surface water (b) groundwater

A study is also carried to evaluate the concentration of fluoride in various dumping locations of the city. GIS maps are prepared to show the distribution of fluoride concentration in the dumping waste site. In this study, we have collected samples from domestic, commercial, industrial, or municipal waste dumping sites. The locations having fluoride concentration beyond its permissible limits are found in municipal, commercial and industrial waste sites. The fluoride content in the domestic waste site is found within its safe range. This has shown that there is a high probability of the presence of fluoride content substances in the garbage dumped by municipal, commercial establishments, and the industries which might have eventually increased the fluoride concentration in the river water. Figure 8 shows the map of fluoride concentration, above the permissible limit of the (a) municipal dumping site, (b) commercial dumping site, and (c) industrial dumping site. The point source of the concentration is shown with red circles, whereas the large circle represents high fluoride concentration and the small circle with a low concentration source. It may be noted that some of the dumping locations are not near the river. However, these dumping sites are well connected to the river through city drains. As such, the pollutant dumping at these sites is also polluting the river water.

We also conducted $t-$ statistic analysis to find the similarities between the fluoride concentration of river water and that of groundwater. The null hypothesis (H_o) is that the mean of both the sources is the same.

Table 3 shows the t statistics for 95% confidence values for all the thirteen locations. It may be observed from the table is that for a 95% confidence level, the null hypothesis is accepted for locations L9, L10, L12, and the hypothesis is rejected for the other locations. This shows that there is a strong correlation between the concentration of fluoride of surface water and groundwater for locations L9, L10, L12.



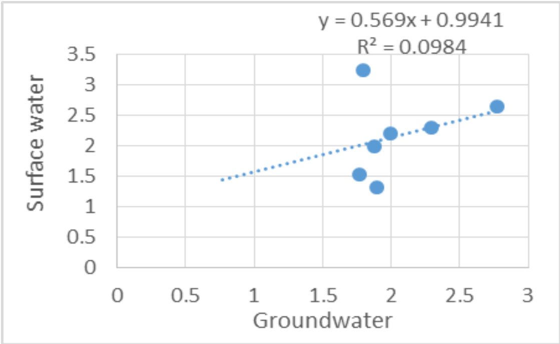
(a) (b) (c)

Fig. 8. Map showing the fluoride concentration (above the permissible limit) a) Municipal (b) Commercial and (c) Industrial dumping site

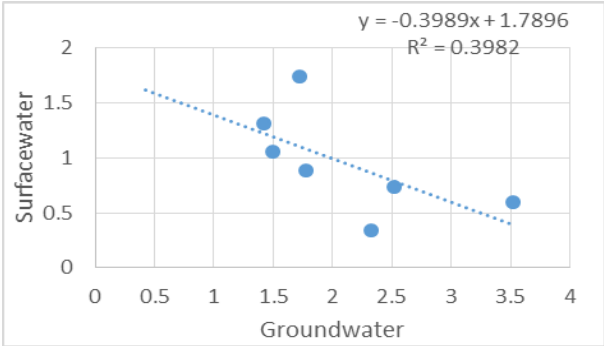
Table 3. *t* statistics value at 95% confidence

Location	t	$p-$ value	Location	t	$p-$ value
L1	-0.8200	0.4282	L8	-0.7500	0.4695
L2	0.4129	0.6908	L9	-0.0305	0.9761*
L3	0.5767	0.5748	L10	0.0386	0.9699*
L4	-0.9437	0.3625	L11	1.4576	0.1707
L5	-0.3525	0.0053	L12	-0.0211	0.9835*
L6	0.3387	0.7407	L13	-0.3723	0.7180
L7	-1.6328	0.1332			

A statistical analysis has been carried out to find out the correlation between surface water and groundwater fluoride concentration by using the linear correlation method. Out of the 13 sampling locations, 7 locations are selected where the fluoride concentration has exceeded its permissible limit. The regression equations were derived, taking groundwater fluoride concentration as the dependent variable and surface water fluoride concentration as an independent variable, respectively. Figures 9 (a-g) shows the scatter plots, where the concentration of fluoride obtained from groundwater is plotted along the x-axis, and that obtained from surface water is plotted along the y-axis. From the figure, it has been observed that in Beltola, Rukminigaon, Fatasil, and Bharalumukh location, a poor correlation has been obtained between the groundwater and surface water fluoride concentration. It has been noticed that the fluoride concentration both in groundwater and surface water is above the permissible limit. However, due to the presence of two outlier data, a poor R^2 has been obtained. A medium correlation with R^2 value 0.6 is observed in Athgaon and Sluice gate location. Whereas, a strong correlation (R^2 $\geq$0.9) is observed in Chabipool location.



(a)



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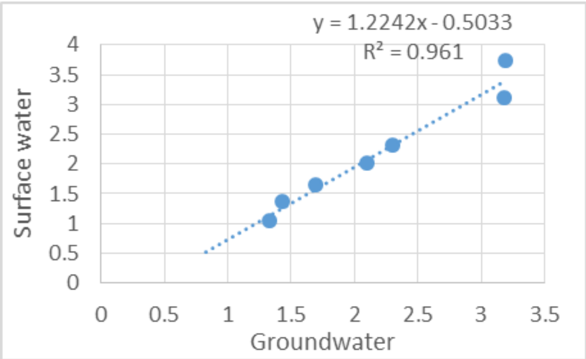

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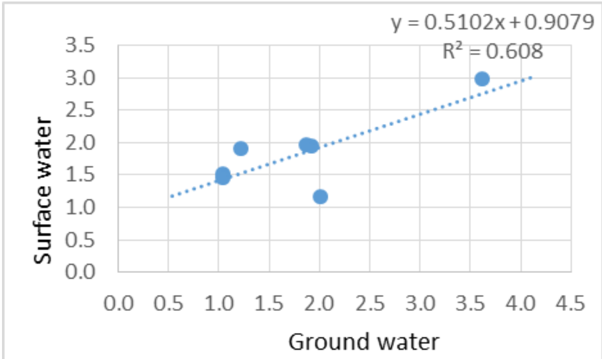

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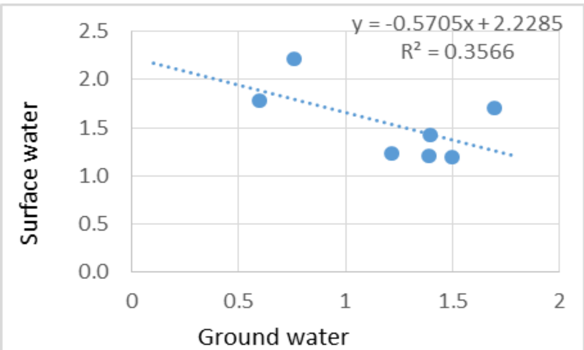

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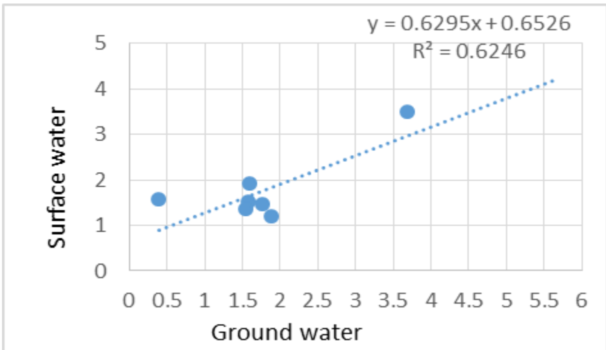

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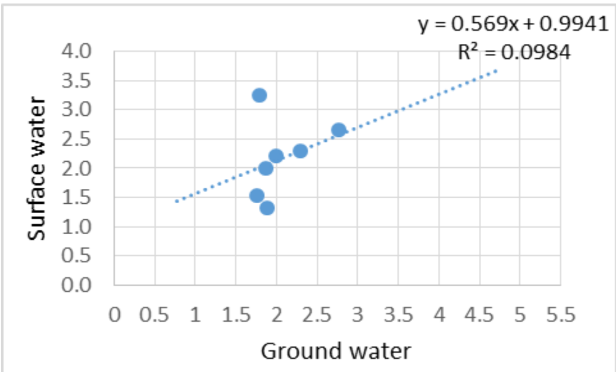

(g)

Fig. 9. Scatter plots of fluoride concentration between groundwater and surface water a) Beltola b) Rukminigaon c) Chabipool d) Athgaon e) Fatasil f) Sluicegate and g) Bharalumukh location

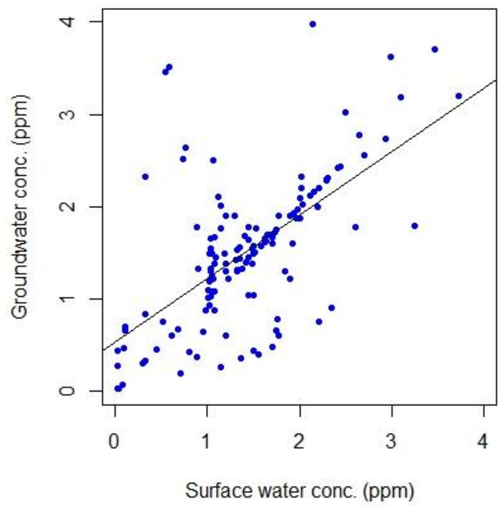

Fig. 10. Scatter plot of fluoride concentration between groundwater and surface water when all the considered together

Table 4. Regression parameters with standard error and t statistic values

Coefficient	Estimate	Standard Error	t	$p -$ value
Intercept	0.53567	0.11717	4.572	1.06e-0.5
Surfacewater (X)	0.68725	0.07331	9.374	<2e-16

We also conducted a regression study considering all the data together. Figure 10 shows the scatter plot of fluoride concentration between groundwater and surface water when all the considered together. The regression parameter, standard error, and the t statistic values are shown in Table 4. The standard error for the intercept and X is low and can be accepted. For the t statistic analysis, the null hypothesis (H_o:) is that the coefficients of the regression equation is zero. For a 95% confidence level, the $p -$ value is quite low, and the null hypothesis is rejected. The R-value is 0.62. which shows that there is a good correlation between the concentration of fluoride of groundwater and surface water. Thus, it can be concluded that there is an interaction between the surface and groundwater in some locations, and the polluted river water has contaminated the groundwater aquifer.

CONCLUSIONS

The fluoride content in both river Bharalu water and in groundwater has been obtained as per the standard method prescribed by APHA (1995). From the investigation, it has been observed that the concentration of fluoride is varying from 0.02 to 3.73 mg/l in river water and 0.04 to 4.7 mg/l for groundwater. The result indicates that the fluoride level exceeds the permissible limit of 1.5 mg/l in almost all the sampling locations of Guwahati city. For the dumping location sites, the locations having fluoride concentration beyond its permissible limits are found in Municipal, Commercial, and Industrial waste sites. The fluoride content in the domestic waste site is found within its safe range. A good correlation between surface and groundwater fluoride concentration is noticed in some locations, which shows that contaminated river water might have entered into the groundwater aquifer.

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CONFLICTS OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. Also, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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