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Spatio-Temporal Pattern of Groundwater Arsenic Concentration in Thick Unconfined Aquifer of Murshidabad District, West Bengal, India

Ghosh Tathagata and Kanchan Rolee*

Department of Geography, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat-390002, India

***Corresponding author: roleekanchan@gmail.com**

Abstract:

Groundwater is one of the major sources of drinking water in several parts of the world. At the same time it is associated with contamination and health issues. Arsenic contamination of groundwater is one of the major concerns among them. In India, many parts of West Bengal plain are severely affected by Arsenic concentration. From the severity of the problem the utmost priority is to identify the major hot spots of the arsenic concentration. To evaluate the behavior of arsenic in groundwater both in terms of spatial and temporal aspect, samples are collected from the unconfined aquifer of Murshidabad district of West Bengal, for three following years in different seasons. An important relationship is found between the arsenic concentration, rainfall intensity and the subsurface lithology.

Keywords: Arsenic, Subsurface lithology, Unconfined Aquifer

1.0 Introduction:

Beginning of late twentieth century marks the rapid increase of groundwater consumption throughout world (Ravenscroft *et al.,* 2009). With the increasing intensity of extraction, the quality of groundwater can deteriorate to some extent. Several parts of the world experiences groundwater contamination due to mixing of different minerals both naturally and due to human activities (Onodera *et al.,* 2008). Although minerals in groundwater are necessary for human health, but to a certain limit. Above the permissible limit it may create health problem which may range from mild to severe depending on the duration and exposure (Kanchan and Roy, 2009, Hung *et al.,* 2004). Among these minerals arsenic is considered as the problematic, even when consumed in lower quantities. World Health Organisation has set 0.05mg/l as the permissible limit in water for drinking (Chakraborti *et al.,* 2008). The first case of arsenic poisoning was reported from Poland in 1898 (Mandal and Suzuki, 2002). The arsenic contamination cases were even reported from Canada (Wyllie, 1937) and New-Zealand in mid-twentieth century (Grimmett and McIntosh, 1937). Taiwan also attracts the attention of several countries in respect of arsenic contamination. Bangladesh, located in the Padma-Meghna-Brahmaputra plain, shows that in 41 of 64 districts (1998) arsenic level in groundwater was above 0.05mg/l (WHO, 1993). In Indian subcontinent Bengal plain have the highest concentration where almost 50% of total area is contaminated.

Several parts of Jharkhand, Uttar Pradesh, Assam valley experience the occurrence of arsenic in groundwater (Chakraborti *et al.,* 2004). The recent studies shows nine districts of West Bengal namely Malda, Murshidabad, Budwan, Nadia, Hoogly, Howrah, Kolkata, North 24 Parganas and South 24 Parganas, among 19 districts are severely affected by arsenic concentration (SOES). Long term exposure to arsenic may creates different health effects like melanosis, keratosis, black and white pigmentation, gangrene and in the most harsh cases cancer of lungs and bladders (Smith, Lingas and Rahman, 2000; Hossain *et al.,* 2004, Cavar *et al.,* 2005;Sun et *al.,* 2006, Ahamed *et al.,* 2006, Villaescusa *et al.,* 2008, Roychowdhury *et al.,* 2010). In the last two decades thousand of water samples were collected from different parts of India and many showed the presence of arsenic above permissible limit. (Chakraborti *et al.,* 2002). From the severity of the problem the utmost priority is to identify the major hot spots of the arsenic concentration and also spot out the risk free zones. In this context variation of arsenic concentration in groundwater is one of the major concerns of among different scholars. (McArthur *et al.,* 2001, 2004; Kinniburgh and Smedley, 2001; Cheng *et al.,* 2005; Wagner *et al.,* 2005; Gonçalves *et al.* 2007; Savarimuthu *et al.* 2006) Present paper restricted to find the spatial and temporal variation of arsenic in groundwater in Murshidabad district, west Bengal, India.

1.1 Source and Mechanism of Arsenic Mobilization in Bengal Basin and Ganges Delta:

Major four types of mechanism through which arsenic mobilized into the groundwater are recognised. These four mechanisms are more or less dependent upon the geological and climatic setting and both of them are inseparably associated with each other. Reductive dissolution, alkali desorption, Sulphide oxidation, geothermal are major for mechanism of natural arsenic concentration in groundwater (Ravenscroft *et al.,* 2009). Several studies illustrate the arsenic in Ganges delta is originated from sulphide mineral (Harvey *et al.,* 2005). Workers like Mallick and Rajgopal (1996), Das *et al.,*(1996), Mandal *et al.*(1998) hold the hypothesis of oxidation of pyrite that is released in to the groundwater due to excessive withdrawal of water. On the other hand researcher like Acharyya *et al*. (1999, 2000, 2005) support the concept of comparative ion exchange with phosphate from fertilizers. At the same time other researchers argued that the source of dissolved phosphate is not from the fertilizers (McArthur *et al.,* 2001). Reductive dissolution of iron mechanism was first documented by Bhattacharya, Chatterjee and Jacks (1997) and further accepted by others (McArthur *et al.,* 2001, Harvey *et al.,* 2005). The main mechanism of reductive dissolution is mobilization of arsenic sorbed to iron(oxy)(hydr) oxides. (Nickson *et al.,* 2000). Scholar like Zheng *et al.,* (2004) combine Oxidation of pyrite and Reductive Dissolution, and proposed new mechanism of Reduction and oxidation. The concept was accepted and elaborated by Mukherjee and Fryar (2008).

2.0 Materials and Methods:

2.1 Study Area:

Murshidabad district is situated in the flank of River Ganga. One of the major tributary, Bhagirathi passes through the heart of the district. The geographical extent of the district is 24^0 50' 20" to 23^0 43' 30" N and 87^0 46' 17'' and 88^0 46' 00'' E (Fig. 1). The eastern part of Bhagirathi exhibits younger alluvium where as the western part is associated with older alluvium mainly lateritic. The study area in the present study is confined to the eastern part of river Bhagirathi. Only thick unconfined aquifer is taken into account to investigate any relationship between the source of water from the surface in the form of rainfall and variation in the level of arsenic concentration.

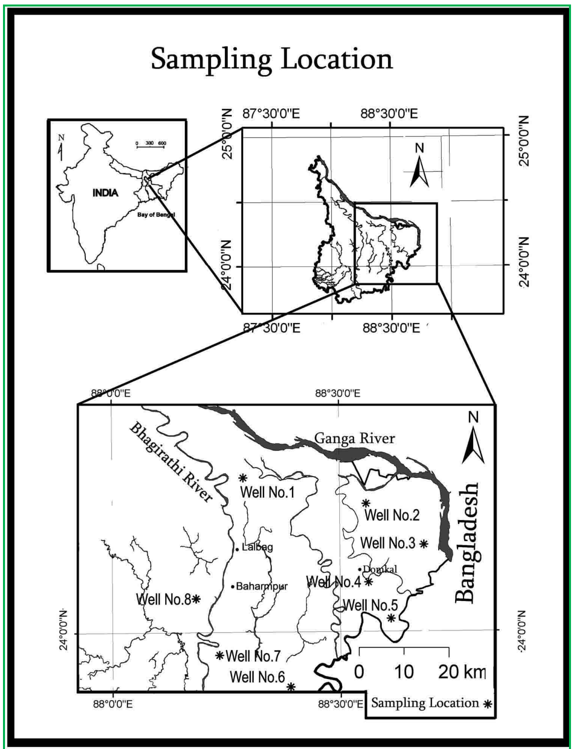

Fig. 1

2.2 Hydrogeological Setup:

The West Bengal part of Bengal Basin has sedimentary deposition from Mesozoic to Recent age. Ganga- Brahmaputra river system contributes in building up the Bengal delta. Even in the Tertiary these rivers carries a considerable amount of sediments from Himalaya (Stüben *et al.,* 2003). The study area experience the recent alluvium deposition resulted by the extensive fluvial processes (Morgan and McIntire, 1959). Sedimentologically the Bengal Delta is characterized by thick accumulation of clay layer which is in some places overlain by silt sand and gravel deposits (Deshmukh and Goswami 1973). The upper part of the Bengal plain reveals three inter connected aquifer system. The shallowest aquifer extends upto the depth of 12-15 m, typically made of sub angular, fine to medium grained sands and clay lenses. The shallow aquifer shows mixed igneous and metamorphic provinces for the eroded deposited minerals. The intermediate aquifer extends from 35-46 m and mainly metamorphic type of minerals can be observed where as the lower aquifer extended from 70 to 150 m with magmatic province. (Stüben *et al.,* 2003). The eastern part of Bhagirathi River is composed of thick unconfined aquifer.

Table 1: Location of Sample Wells

Well ID.	Block	Location Name	Depth (ft.)	Longitude	Latitude
Well No.1	Bhagwangola-1	Shyampur	85	$88^o17'05''$	$24^o20'10''$
Well No.2	Raninagar-2	Kadamtala	85	$88^o52'29''$	$22^o43'08''$
Well No.3	Jalangi	Khayramari	85	$88^o38'50''$	$24^o11'52''$
Well No.4	Domkal	Harurpara	85	$88^o38'12''$	$24^o03'16''$
Well No.5	Domkal	Rajapur	85	$88^o38'12''$	$24^o03'16''$
Well No.6	Nowda	Chandalati	85	$88^o27'32''$	$24^o52'55''$
Well No.7	Beldanga-1	Mokrampur	85	$88^o15'32''$	$23^o56'22''$
Well No.8	Baharampur	Beuchitala	85	$88^o22'46''$	$24^o06'06''$

The western part of the river has thick semi confined aquifer and the northern most part exhibit unconfined type of aquifer. The overall direction of groundwater flow is from north-west to south-east. (Das et *al.,* 1994). The present study is mainly confined in the thick unconfined aquifer mainly lying in the eastern part of Bhagirathi River (Fig. 2).

Objective:
Main objective of this paper is to investigate the spatial and temporal variation of arsenic concentration in the thick unconfined aquifer of Murshidabad district.

2.3 Methodology:

2.3.1 Data Collection and Sample Analysis:

Eight sample spots were selected through random sampling in the eastern part of River Bhagirathi and were collected for three successive years between 2009 to 2011 in premonsoon , monsoon and winter seasons. In Murshidabad district the duration of rainfall is long. Rain starts from the month of May and extends upto October. The samples in the present study have been chosen considering the rainfall pattern. One of the samples has been collected in the months of July (monsoon), the other in December (winter) and the third in February (premonsoon) (Table-1). Thus six times samples have been taken in to consideration. Garmin E-trex Vista HCx® handheld GPS was used for marking the location of tube wells and data were tripped through Mapsource Software® in Computer. Groundwater of the selected spot tube wells were collected in 250ml Capped Polyethylene bottles acidified with HNO_3 for prevention from any bacterial growth.

2.3.2 Instrumentation and Glassware:

Elico Double Beam UV-VIS Spectrophotometer Model S1-210 was used in detection the arsenic concentration in water samples. Pyrex evolution vessel was used for arsenic extraction from the water samples. All of the glass utensils (Borosil) are thoroughly cleaned in different stage of experiment to prevent from any impurities.

2.3.3 Regents:

All the reagents in the experiment are analytical grade and double distilled water (Aquapure) is used. Standard Molybdenum Blue method for arsenic detection was employed for detection of trace arsenic in water samples (Bassett et al. 1978). Stock solutions of As (1000mg/l) are prepared from arsenic trioxide (As_2O_3), Loba Chemical pvt. Mumbai, India, with proper dilution. Highly pure Hydrochloric Acid (35-38%) (SD Fine Chemical Limited, Mumbai, India) is used at different levels of the experiment. Further, Potassium Iodide (KI), Tin(II) Chloride ($SnCl_2.2H_2O$), Zinc granules (Zn), Iodine, Sodium Bisulphite (SO_2), Sodium Hydrogen Carbonate ($NaHCO_3$), Hydrazinium Sulphate ($NH_2.NH_2.H_2SO_4$) and Ammonium Molybdate ($(NH_4)_6Mo_7O_{24}.4H_2O$) are obtained from Mark India Limited, Mumbai.

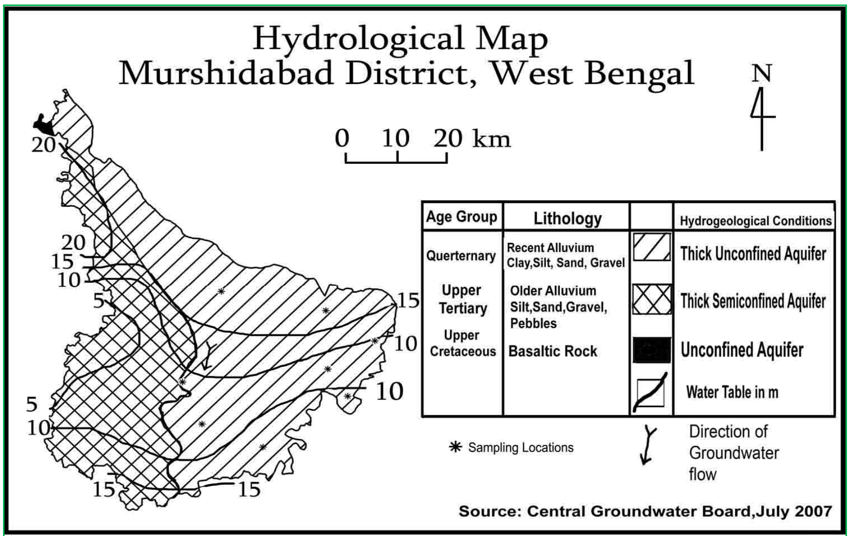

Fig. 2

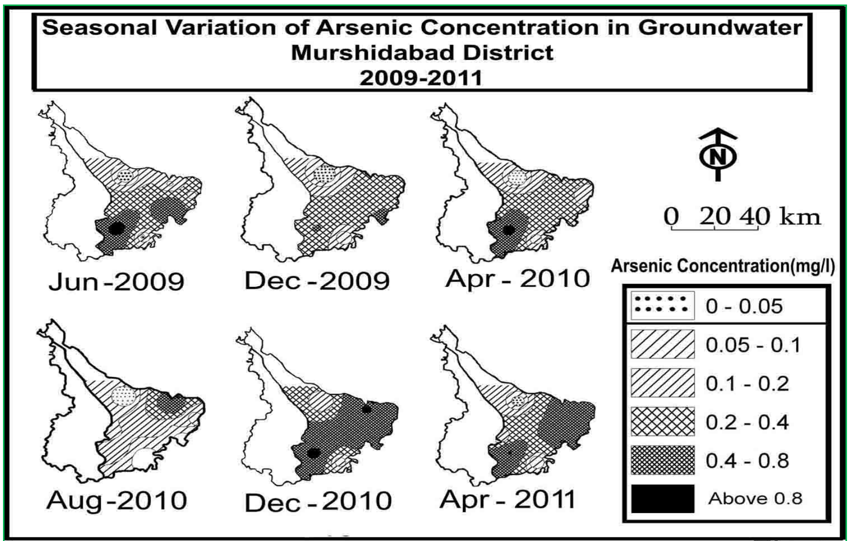

Fig. 3

Table 2: Concentration of Arsenic (mg/l) in Wells in different Seasons

Well ID	Monsoon 2009	Post-monsoon 2009	Pre-monsoon 2010	Monsoon 2010	Post-monsoon 2010	Pre-monsoon 2011	Mean
Well No.1	0.012	0	0	0.004	0.051	0.020	0.014
Well No.2	0.087	0.210	0.210	0.696	0.834	0.456	0.415
Well No.3	0.181	0.290	0.140	0.073	0.630	0.677	0.331
Well No.4	0.458	0.520	0.361	0.012	0.421	0.400	0.362
Well No.5	0.632	0.337	0.352	0.094	0.602	0.614	0.438
Well No.6	0.036	0.050	0.050	0	0.040	0.021	0.032
Well No.7	1.000	0.420	0.907	0.130	0.913	0.820	0.698
Well No.8	0.236	0.230	0.378	0.087	0.425	0.093	0.241

Table 3: Mean Monthly Rainfall (mm) of Murshidabad District

Year	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec
2009	0.2	0	24.4	0	176.6	73.8	185.8	358.5	381.6	150.7	0	0
2010	0.2	0.1	0	0	88	263.5	100.9	171.3	174.4	89.9	2.0	50.4

Source: Indian Meteorological Department

3.0 Results and Discussion:

3.1 Spatial Pattern:

The level of arsenic is much higher than the permissible limit throughout the thick unconfined aquifer zone in all the seasons (monsoon 2009 to premonsoon 2011). Fluctuations are keenly observed in Well No.7, 8, 4, 5 and 3 where concentration varies between 1mg/l to 0.01mg/l. Contrary to this condition, consistency in the level is noticed in Well No.1 and Well No.6 blocks. In these two points the concentration of arsenic is below the permissible limit (0.05mg/l) in all the seasons. Fluctuations can be observed in the entire aquifer except in the two peripheral points laying in the extreme north and south (Table-2) (Fig. 3). Lithology of the area is helpful in explaining the pattern of arsenic concentration. In several parts clay layer is noticed in the upper part of the aquifer. Clay layer plays an important role in restricting the infiltration of water to the subsurface and act as an Aquitard.

Table 4: Mean Rainfall (mm) in different seasons

Year	Premonsoon (February to April)	Monsoon (May to October)	Winter (November to January)
2009	8.10	221.16	0.06
2010	0.03	148.00	52.7

In the eastern and the western part of this aquifer the layer of clay is either discrete, thin or absent. Contrary to this in the northern and southern part presence of clay layer is much more prominent (Mukherjee *et al.,* 2007). In the former condition water can easily infiltrate through the layers. In this condition dilution effect during monsoon season and drying effect during winter and premonsoon season are much more prominent leading to fluctuation. Such a phenomena is seen in Well No.7, 4, 5 and 8. Opposing to this presence of clay layer restrict easy infiltration of rainwater which delays the process of dilution and thus a consistent state is observed in Well No.1 and Well No.6 (Fig. 4).

3.2 Temporal Pattern:

Variations are noticed in the amount of rainfall in the years 2009 and 2010. The mean rainfall is 112 cm where as in 2010 it is just 78 cm (Table-3). Similar pattern is seen in the average rainfall of different seasons (2009-2011) (Table-3) (Fig. 5). Mean rainfall in 2009 (221.16 cm) and 2010 (148 cm) shows a decreasing trend during the monsoon season of 2010 (Table-4). In the premonsoon and winter seasons mean rainfall decreases considerably. 2009 monsoon data is taken in the month of July, which is just the onset of the heavy persistent rain period. The elevated amount of arsenic in the groundwater during 2009 monsoon is associated with it. (Fig. 6) Arsenic concentration fluctuation during these seasons is correlated in terms of its concentration. Definite relationship between the behavior of arsenic and rainfall intensity exists. With increasing rainfall intensity rate of dilution increases which minimizes the arsenic concentration in the groundwater (Farooq *et al.,* 2010). During monsoon period there is considerable decrease in the arsenic concentration. In monsoon 2009 the concentration varies between 1 to 0.01mg/l where as in 2010 the concentration rages between 0.69 to 0.004mg/l. In the case of Well No.7 (1mg/l) arsenic concentration does not vary significantly throughout the time (Fig. 7). This can be considered as the only exception. Thus it can be said that there is a strong correlation exists between rainfall condition, dilution effect and arsenic concentration. Contrary to this, during winter season and premonsoon seasons there is an increase in the concentration which is associated with the decrease in dilution effect. Lesser presence of rainwater in the aquifer triggers the mechanism of releasing arsenic in the shallow aquifer during Premonsoon and winter season. Well No.2 shows completely different pattern where during the monsoon 2010 shows concentration as high as 0.69mg/l and in winter 2010 it is 0.83 mg/l (Fig. 8). This type of pattern might be attributed due to local circumstances of the aquifer.

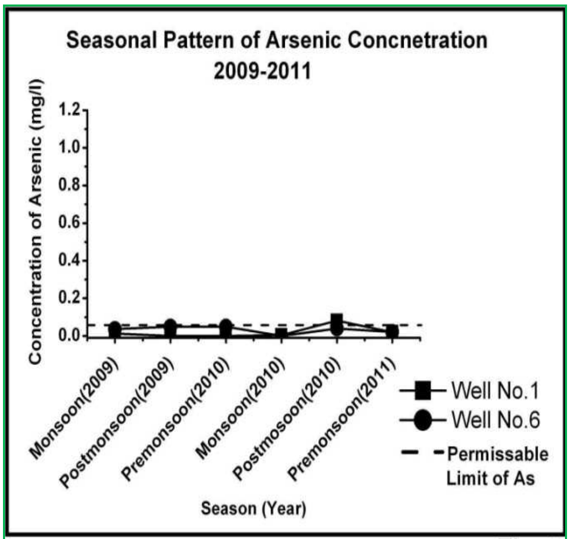

Fig. 4

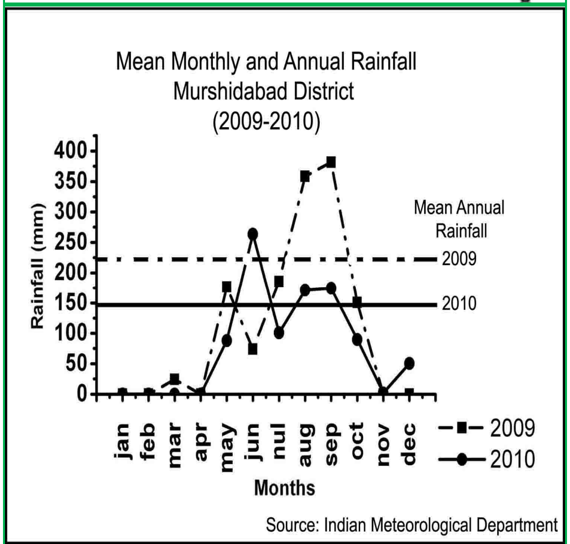

Fig. 5

4.0 Conclusions:

1. There is a prominent seasonal variability in the arsenic concentration in different wells in three different seasons.
2. There is an inverse relationship is found between the rainfall intensity and arsenic concentration.
3. The type of behavior of Arsenic is correlated with the subsurface lithology and layer of clay which is found to be an important parameter.

5.0 Acknowledgement:

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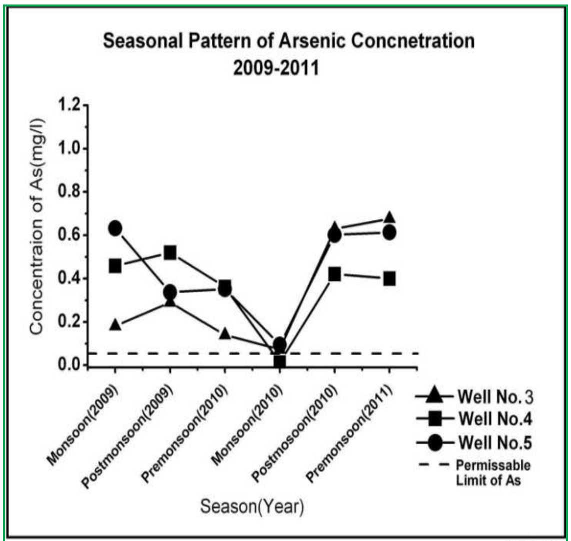

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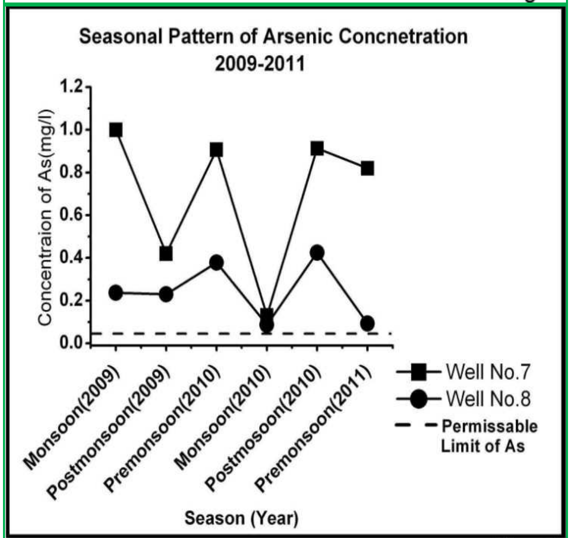

Fig. 7

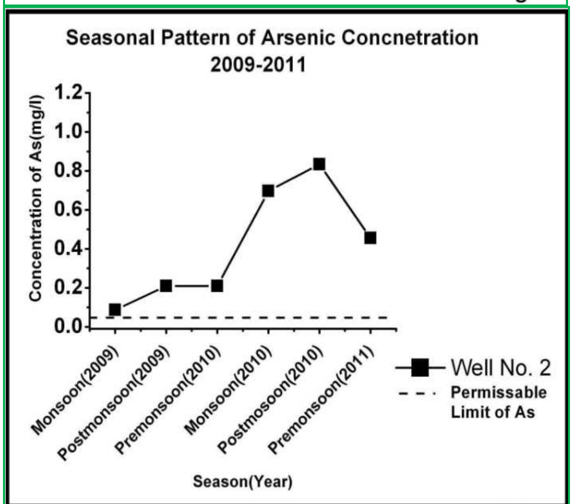

Fig. 8

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